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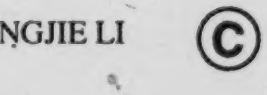
OPTIMIZING DRINKING WATER FILTRATION

BY

HONGJIE LI 

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(signed) Hongjie Li

10427-13 Av.
Edmonton, Alberta
T6G 6E3

Dated: January 26, 2000

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled: OPTIMIZING DRINKING WATER FILTRATION submitted by: Hongjie Li in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING.

Stephen J. Stanley – Supervisor

Ian D. Buchanan

Suzanne M. Kresta

Date January 24, 2000

Abstract

Six polymers and four types of filter-media were investigated in a pilot plant filtration system to optimize the performance of filters at the Rossdale water treatment plant in Edmonton, Alberta for unsoftened water filtration. Types and doses of polymers, mixing intensity, and filter headloss and effluent flow rate were tested to evaluate the performance of filters. On-line turbidimeter and particle counter were used to monitor the influent/effluent water quality and a computer system (WQS Vista) was used to record the experiment data (particle counts, turbidity of each filter, and pH) every five minutes. Results showed that the polymer-aid filtration improved the effluent water quality greatly, especially the medium-molecular-weight, cationic polymers. The particle removal and filter run length were affected mainly by the polymer types, mixing intensity, and influent water quality. Mixing intensity affected the coagulation and flocculation of polymer-particles, then controlled the filter run length which is related to headloss development and effluent flow rate of filters.

In this study, mono- (quartz sand, fine sand) and dual-media (anthracite-sand, and GAC-sand) filters were used to investigate the effect of filter media on polymer-aid filtration. According to the results of this research, anthracite-sand filter performed better compared to the others in terms of effluent water quality and headloss development. Hence it was able to operate longer.

I dedicate this thesis to

My parents,

My husband,

&

My son

For their encouragement, support, and love.

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List of Symbols

C = the distance between the impeller and the bottom of mixing tank (mm)

D = impeller diameter (mm)

G = velocity gradient, sec^{-1}

GAC = ground activate carbon

N = impeller rotational speed (rpm)

P = input power, watt

PAC = powder activated carbon

T = mixing tank width (mm)

V = volume of water

ZP = zeta potential

ε = power input per unit mass of fluid

γ = absolute viscosity, $N.s/m^2$

μ = kinematic viscosity, m^2/s

1 Introduction

1.1 Background

The purpose of the water treatment processes is to remove a variety of contaminants and produce water that meets or exceeds all standards set for drinking water quality. A group of these contaminants is particulate matter. Particles can be a source of chemical contaminants which are adsorbed to them, be pathogenic organisms, reduce the effectiveness of disinfection and negatively impact the aesthetic quality of the water. The removal of particles is therefore required for both public health and aesthetic reasons. One of the most economical and practical methods to remove particles in water treatment is through the use of conventional treatment processes such as coagulation, flocculation, sedimentation, and filtration.

Coagulation and flocculation are processes for combining small particles into larger aggregates in the water to enhance their removal in sedimentation and filtration. It is by far the most widely used process for the removal of substances producing turbidity in water. If water has high turbidity, sedimentation is often used to reduce the quantity of material before entering the filter. The purpose of filtration is to produce low turbidity effluent water.

With the implementation of more stringent turbidity standards and the consideration of health impacts of microbial contaminants in drinking water, more emphasis is now given to particle removal. This shows a necessity for improving the performance of water treatment processes, especially filtration, to meet the more stringent turbidity standards. The Guideline for Canadian Drinking Water Quality (Eco/Log, 1993) recommends a maximum acceptable turbidity of 1 NTU for 95 percent of the operating time of an individual filter. However, Nieminski (1995) recommended that maintaining a filtered water turbidity less than 0.2 NTU can effectively remove *Giardia* and *Cryptosporidiun* cysts. The Province of Alberta adopt that the turbidity is less than 0.5 NTU from plant reservoir effluent. In Edmonton, an internal guideline of less than 0.1 NTU has been set and the particle counts are less than 50 particle/mL for individual filters. (Summary, 1999).

1.2 Problem Statement

The Rossdale water treatment plant in Edmonton, Alberta, Canada, has the following major processes: coagulation, flocculation, sedimentation, softening, filtration, and disinfection. Currently, studies are being conducted to determine the impact of removing the softening process on the filtration process, due to the changes in filter influent water quality. In order to keep or improve the effluent water quality in response to the changes of influent water quality, some improvement must be made to the filtration process. The investigation of pilot-scale filters as a means of predicting the performance of the full-

scale plant in response to the changes in control variables will be valuable in selecting the best filtration conditions to improve the effluent water quality. This is the major objective of this study. Existing mathematical models do not allow the estimation of finished water quality based on filter operating parameters. Therefore, pilot-scale experiments are recommended for the filter performance (Davis, 1983).

The Rossdale water treatment plant uses particle counters to monitor the effluent water quality because it is a more sensitive instrument than a turbidimeter. In order to meet the effluent water standards, Rossdale water treatment plant is studying the difference in using dual-media and crushed quartz sand filters as well as using polymers as filter aids.

The polymers as filter aids not only maximize the removal of particulate matter, but can also lead to improvement in a variety of other water quality parameters which are characterized by less conventional parameters (Dentel, 1991).

Unfortunately, there are a large number of polymers that can be selected as filter aids. A report (AWWA Committee report, 1982) showed that there are 48 different polymers used in 336-water treatment plants in the United States. Over 1100 polymers by name were approved by the US EPA and can be used in water treatment. These polymers range over a whole spectrum of molecular weights, types of charges, and charge densities. Therefore, the selection of polymers as filter aids is a significant challenge. In different water treatment plants, the influent water quality and the operating conditions for filtration are so different that it is not easy to select polymers based only on experience.

This study is mainly focused on the selection of polymers and dosage optimization as well as filter media for the treatment of unsoftened water. The study was conducted using a filtration pilot plant located at the Rossdale water treatment plant.

1.3 Research Objective

The Rossdale water treatment plant plans to remove the softening unit, so the water quality that enters the filtration unit will change. With this change, concerns have been raised whether the excellent effluent water quality that the plant currently provides can be maintained. To answer the concerns, a series of improvement must be made to the filtration unit.

The main objective of this study is to improve filtration effluent water quality by using polymer-aided filters to decrease the turbidity and particle counts of filter finished water to satisfy the standard of effluent water quality. In this study, the influent water was unsoftened water coming from the clarifier. To accomplish the above objective, the following details were considered:

(1). Compare the pilot-plant with full-scale filtration;

(2). Compare the effluent water quality between softened water and unsoftened water;

(3). pH adjustment with no polymer filtration;

(4). Select the optimum polymer types and dosages;

(5) Investigate the effect of polymer types and dosages on effluent flowrate, headloss, and filter run time;

(6). Investigate the effect of mixing rate on filter run;

(7). Study the effect of powder activated carbon on filtration water quality; and

(8). Compare different filter media.

2 Literature review

The literature review summarizes the mechanisms of filtration, types of polymer aids for filtration, the major factors that affect filtration, and some control and monitoring methods of filter finished water quality.

2.1 Particles in Natural Water

Particles in natural water vary widely. They may be mineral (clays, salts, and asbestos fibers) and organic (viruses, bacteria, and algae). When dealing with the coagulation process, small particles (10^{-8} to 10^{-4} m in diameter) are mainly considered and these particles are suspended. Most suspended small particles in water have negatively charged surfaces (Hunter, 1979; Niehof, 1972). The negatively charged particle is surrounded by a diffuse layer to form a suspended stable particle in water. In this condition, the particle has a slow aggregation or flocculation rate. The phenomena may be explained by the following mechanisms: (1) electrostatic repulsive interactions due to diffuse electrical double layers, (2) hydrophilic effects due to bound water at particle surfaces (Edzwald, 1993), and (3) steric effects due to adsorbed macromolecules (Edzwald, 1993; Lyklema, 1978).

Particles producing turbidity are often inorganic. Their sizes may range from molecular dimensions to 50 μm or larger. The distinguishing characteristic of particles of colloidal dimensions is the high ratio of the surface area to mass. Particles causing taste, odour, and colour are generally organic compounds. Humic substances are the major organic constituent. They are anionic polyelectrolytes (negatively charged) of low to moderate molecular weight. For further detail of particle characters, refer to Dempsey (1984).

All colloid suspended stable particles in water may be destabilized by adding suitable chemicals called coagulants, which have positive charges. The destabilized particles can be aggregated through flocculation to form larger flocs, which can be settled by gravity.

In filtration, the charge, floc size and density of particles are the most important characteristics. The charge of particles can be measured by Zeta Potential (ZP). The particle size affects the performance of filtration. Yao et al (1971) found that a critical size of about 1 μm has the minimum transport efficiency. For smaller particles (size < 1 μm), diffusion plays an important role, whereas for larger particles, sedimentation becomes dominant. Some researchers (Boyd and Ghosh, 1974; Shull, 1967) also found that when the ZP of a particle is close to zero, the removal efficiency reaches optimum.

2.2 Mechanisms of Filtration

Filtration processes in conventional water treatment plants generally use rapid granular-bed filters. The filter beds commonly contain a substantial depth of sand or anthracite

coal or combinations, and are hydraulically controlled by constant rate or declining rate filtration.

The depth filtration involves a variety of complex mechanisms to remove the suspended particles. The filtration mechanisms are influenced by the physical and chemical characteristics of the suspension, the filter media, the rate of filtration, and the operating method of the filter.

Amirtharajah (1988) determined that particle removal in filtration can be described by the mechanisms of transport, attachment, and detachment. These mechanisms are still used today to analyze the filtration processes. Filtration mechanisms and typical filter pore are illustrated in Figures 2.1 and 2.2 at the end of this Chapter (McEwen, 1998).

2.2.1 Transport Mechanism

O'Melia and Stumm (1967) were the first researchers to describe the factors controlling particle transport in filtration, and they used the following two steps to describe the process: a transport step, and an attachment step. Ives (1969) took a similar approach and defined the role of the transport mechanisms as the provision of forces that will cause the particles to leave their carrying stream lines and to approach the media grain surface where attachment forces can be effective. Mintz (1964) suggested the third step, detachment, which considers that retained particles are being detached as long as new particles are being supplied.

Two physical mechanisms are mainly responsible for particle transport that,results in particles leaving their carrying stream lines in the water filtration: diffusion and sedimentation (Habibian and O' Melia, 1975). Diffusion is transport resulting from random Brownian motion by bombondment of the particles by molecules of water. It is stochastic in nature and becomes more important for particles smaller than 1 μm. Yao et al (1971) concluded that a particle about 1 μm in size had the minimum chance to approach the grain surface in a porous bed as shown in Figure 2.3, whereas smaller particles are mainly transported by diffusion and larger ones by interception along stream lines and by gravity forces,

The mechanism of sedimentation is due to the force of gravity and the associated settling velocity of the particle, which causes particles to cross stream lines and reach the filter grains. For this mechanism, particle size, density and water temperature play important roles. For particles greater than 1 μm in size (for a size range of 5-25 μm), the sedimentation mechanism dominates the particle transport (Habibian and O' Melia, 1975).

2.2.2 Attachment Mechanism

The attachment mechanism involves either electrostatic interactions, van der Waals forces, or surface chemical interactions (O'Melia and Stumm, 1967). It depends on physicochemical mechanisms. Two models have been used to describe the mechanism: the double-layer model, and the bridging model. The double-layer model is based on an

interaction between the electrostatic repulsive forces and van der Waals attractive forces; the bridging model explains effects resulting from chemical bonding and bridging of the suspension particles and the medium through their reaction with the flocculant.

From the research related to chemical factors (O'Melia and Grapps, 1964; Ives and Gregory, 1967; Wnek, 1974), it can be concluded that the type of coagulant is one of the most important chemical parameters in granular media filtration of a given water. The type of chemical used determines which attachment mechanism is dominant. When a repulsion-attraction mechanism applies, usually associated with the use of metal salts as a coagulant, different chemical factors affect the removal process, including the dose of coagulant, the presence of cations, anions, and the water pH. When the bridging mechanism applies, normally associated with the use of polymers, the specific characteristics of the flocculant, adsorption ability, chemical length and molecular weight, and electrostatic charge affect the process (Vner Adin, et al. 1979).

2.2.3 Detachment Mechanism

Detachment of particles attached to the filter media results from scour due to increased interstitial velocity gradients in the bed or as a result of floc shearing. Its magnitude is dependent on the influent concentration, the length of filter run, and the hydrodynamic forces. It should be noted that the mechanisms of attachment and detachment may occur simultaneously and the detachment mechanism often controls the effluent particle concentration and particle size distribution because the significant portion of particles in the effluent come from the detached flocs (Ginn et al., 1992).

Melissa et al. (1993) reported that detachment of previously retained particles or flocs is a factor (perhaps the dominant factor) contributing to filter breakthrough. Particle detachment is predominant in intermediate and large size ranges. Detachment tends to increase with increasing particle size throughout most of the size range.

2.3 Organic Coagulants as Filter Aids

2.3.1 Polymer as Filter Aids

Organic coagulants, called polymers, used in water treatment are linear water soluble high-molecular-weight (about 10^7) organic compounds which have long organic chains and sub-units containing ionizable groups. The flexibility and polyfunctionality of the chain allow the polymer to adopt various shapes or conformational states at the surface, and to be attached to the solid by a number of segment-surface bonds.

Organic polymers are used as coagulants or coagulant aids in many water treatment plants. They have much higher particle removal efficiencies than inorganic coagulants (Prendivile, 1992). The sign of the charge of the polymer ionic groups allows the polymers to be categorized into three groups: anionic, cationic, and nonionic polymers.

Anionic polymers contain negatively charged functional groups. Carboxyl ($-COO^-$) containing anionic polymers are the most important commercial anionic polymers. They are both in the high (10^6 to 10^7) and low-molecular-weight range and have a wide range of charge levels. Cationic polymers are positively charged groups, such as amino ($-^+NH_3-$

), imino ($-CH_2-^+NH_2-CH_2-$) and quaternary amino ($-^+NR_3-$). Normally, they have relatively low molecular weight and are used as filtration aids in water treatment plants (Zhu, 1994). Polymer with no charged groups are called nonionic polymers. These polymers include: polyvinyl alcohol, polyacralein and pure polyacrylamide. Most commercially available "nonionic" actually contain about 1 to 2 % of hydrolyzed amide groups. An AWWA report (1989) concluded that cationic polymers are most commonly used during flocculation and nonionic polymers are most commonly used as filter aids. Table 2.1 shows several examples of polymers as coagulants or filter aids (McEwen, 1998).

Polymers which have both positive and negative charges on the same chain are called amphoteric or polyampholyte polymers. Such polymers have little commercial use in water treatment.

The mechanisms of polymer-particle interactions can be described by charge neutralization, where particle destabilization is attained by the adsorption of opposite-charged polymers on particle surfaces and inter-particle bridging occurs. Improvement of attachment efficiency by using the proper type and optimum dosage is a key aspect to improve particle capture efficiency. However, increasing particle capture efficiency may clog the top portion of the filter bed and lead to rapid headloss development. Pilot studies are required to establish optimum types and dosages of polymers as filter aids to overcome the above problem and to suit individual plant conditions.

2.3.2 Factors Influencing Polymer Performance

Factors that affect the performance of polymers as filter aids in water treatment can be divided into the following two categories:

(1) characteristics of polymers such as molecular weight, charge density, and so on;

(2) process conditions such as mixing intensity, mixing time, position of polymer addition, and pH.

2.3.2.1 Characteristics of Polymers

The polymer molecular weight is one of the important factors that affects the efficiency of filter polymer aids. The molecular weight ranges from 1000 to greater than $5*10^6$ when used as coagulant aids in water treatment. Typically, the polymers are divided in: low-, medium-, and high-molecular-weight. It should be noted that the molecular weight given by the manufacture is only an approximate value and different manufactures assign different molecular weight ranges.

A number of researchers (Levine and Friesen, 1987; Hespanhol and Selleck, 1975) report that higher molecular weight liner polymer have longer the chain. They have a greater geometric extension, exposes more active groups, and increases the probability of adsorption and bridging, so that the higher molecular weight polymer typically have better efficiency.

However, Singley (1972) notes that the cationic polymers with low-molecular-weight ($<10^5$) are often used in water treatment for saving cost because it is reported that lower

molecular weight cationic polymers are more efficient than similar molecular weight polymers with negative or no charge

Polymer charge density is another important polymer characteristic. It refers to the concentration of positive or negative charges on a polymer, either as per unit weight or as a percent of potentially ionized monomer content. It is related to polymer type, polymer content, and polymer concentration in water. For positively or negatively charged polymers, the charge density is affected by the pH of solutions (Ghosh et al, 1985). pH can affect the charge of a polymer as well as the solid particles to be aggregated. Generally, most cationic polymers are less affected by solution conditions (pH, ionic strength, and hardness) than other polymers. Anionic polymer posses negative charge only at high pH. Many become nonionic at lower pHs (Dentel et al, 1989). For unsoftened water, following alum addition (or ferric coagulants), the $Al(OH)_3(s)$ floc particles may carry a slight positive charge so that anionic or nonionic polymers may easily absorb (McEwen, 1998). Rice (1974) indicated that a typical polyacrylamide feed is 0.01 to 0.02 mg/L for each 3 mg/L of average quality alum floc. For very coarse filter media or very weak alum floc, it may be necessary to feed as much as 0.05 mg/L for each 3 mg/L floc. Zhu (1994) found that the optimum polymer dose was 0.01 mg/L. When increasing the polymer dose up to 0.03 mg/L, no further improvement in the filtrate quality was achieved in softened water filtration. Overdosing may increase the adhesives of solids to such an extent that they are difficult to remove from the filter in backwashing (McEwen, 1989).

2.3.3 Mixing Intensity

The coagulation/flocculation/sedimentation processes in water treatment depend on the formation of large porosity flocs from the addition of small amounts of material to water. In the filtration unit, polymers are used to improve the effluent water quality, so the mixing of polymers with influent water is an important factor that affects the polymer performance. A survey of a high-rate filtration plant indicated that the rapid mix process is essential to the successful production of high quality water (Cleasby et al, 1989).

Generally, the mixing operations in a water treatment plant include two steps: rapid mixing and slow mixing. The rapid mixing disperses coagulants uniformly and quickly to cause the destabilization of particles. According to Amirtharajan and Mills (1982), it is imperative that the coagulants disperse in the raw water as rapidly as possible (in less than 0.1 second) so that the hydrolysis products that develop between 0.01 and 1 second will be adsorbed and hence neutralize the colloid charge. The slow mixing transforms the destabilized smaller particles into larger aggregates or flocs. Orthokinetic flocculation is the dominant mechanism in most polymer aided flocculation processes. The rate of particle transport is dependent on the mixing rate controlled by the mean velocity gradient (G). G was first defined by Camp and Stein (1943) in terms of power input per unit volume as:

$$G = \left[\frac{P}{\mu V}\right]^{1/2} \qquad (2.3\text{-}1)$$

where P is the power transferred from the stirrer to the suspension (W), μ is the absolute viscosity (Ns/m^2), and V is the volume of the stirred tank (m^3).

Equation (2.3-1) may be expressed as:

$$G = \left[\frac{\varepsilon}{\gamma}\right]^{1/2} \qquad (2.3\text{-}2)$$

where ε is the average rate of energy dissipation per unit mass, and γ is the kinematic viscosity.

Typically, G is often used as a critical parameter for controlling the rate of Orthokinetic flocculation (Amirtharajah, 1991). Stump and Novak (1979) noticed that the cationic polymers in the higher molecular weight range (> 10^5) perform best with intense mixing at 600 to 1000 s^{-1} and lower weight polymers (10^4 to $5*10^4$) do well at G values in the 300 s^{-1} range. Yeh and Ghosh (1981) also found the similar results. They found that the 300 s^{-1} to 650 s^{-1} G value is necessary when low molecular weight polymers are used as coagulants prior to direct filtration, and a Gt (t is optimum rapid-mix mean detention time, s) range from 28000 to 45000 is the best for several polymers. Leu and Ghosh (1988) concluded that an optimum Gt product for the rapid mixing was found to be $2*10^5$ for 3 to 4 minutes. Zhu (1994) found that a mixing intensity around 700 s^{-1} could achieve the best filtration performance in terms of effluent turbidity and filter breakthrough. Actually, the optimum Gt is influenced by the kind of impeller system and the type of chemical system (Amirtharajah, 1991), thus, the effects of mixing intensity on the performance of filtration aids is still quite controversial and has not been quantified.

Recently, the traditional G value was challenged by many researchers (Clark et al, 1994; Stanley and Smith, 1995). They recognized that the root-mean square velocity gradient G

does not represent local mixing conditions within a vessel, particularly in the impeller zone. Some new ideas have been presented in their research. The analysis of turbulence in a mixing vessel allows a more refined specification of flow, energy, and dissipation, which is important to the mixing process, especially to the scale-up of mixing process. So it is very important to study the mixing conditions in a mixing vessel. However in this study, G has been used to describe mixing as it is most commonly used in water treatment applications.

2.4 Destabilization Mechanism and Polymer Properties

Generally, the charge neutralization model and the interparticle bridging model are used to describe the relationship between polymer properties and particle destabilization mechanism.

2.4.1 Charge Neutralization Model

In the charge neutralization model, adsorption and charge neutralization occur when oppositely charged polymers adsorb on particle surface. An example is the destabilization of clay (negatively charged particles) with cationic polymers. This model deals with the use of relatively low-molecular-weight, high-charge-density cationic polymers to destabilize negatively charged particles. The required dosage of polymers is proportional to the charges of the polymer. At the optimal polymer dose, the charge is reduced to near

zero and the polymer is almost adsorbed on the particle surface. Overdosing will cause residual polymer in solution and can lead to steric stabilization.

2.4.2 Interparticle Bridging Model

Destabilization by the bridging model occurs when high-molecular-weight (usually greater than 10^6) polymer adsorbs on one or more sites on the particle surface, thereby linking the particles together. The high-molecular-weight polymer gives sufficient size (chain length) to extend into solution for distances larger than double-layer thickness and attach to other particles. The adsorption is proportional to the particle concentration. Initial mixing is an important factor to avoid localized overdosing. Table 2.2 summarizes and compares the major features of charge neutralization and interparticle bridging models (McEwen, 1998).

2.4.3 Patch Model

Another model that describes filtration is called the patch model (Gregory, 1973), which deals with low-molecular-weight cationic polymers adsorbed onto negatively charged particles. In this model, the polymer molecules adsorb in a flat planar configuration and have uneven distribution of the adsorbed polymers, resulting in "patches" of positive charge. The optimal polymer dose does not have to produce complete charge neutralization because flocs are formed by strong electrostatic attraction between patches of positive charge and "bare" negatively charged areas on the particles. At high particle

concentrations and as the molecular weight of the polymer increases, interparticle bridging may take place because the kinetics of forming bridging are more rapid than those of polymers adsorbing in a flat planar configuration (McEwen, 1998).

2.5 Filter Media

Common filter materials used in rapid sand filtration are sand, crushed anthracite coal, GAC (granular activated carbon), and garnet or ilmenite. These may be used alone or in dual-or triple-media combinations. The most commonly used of these are the sand and dual-media filters. GAC is being used in filter-adsorbers that serve for both filtration and organic compound adsorption. Tables 2.3 and 2.4 list the typical properties of filter media (Pontius, F.W, 1990).

The single-medium filter using coarse sand differs from the conventional sand filter. First, a deeper bed is required to achieve comparable removal of particles because the medium is coarser. Second, because excessive wash rates are required to fluidize the coarse medium, it is washed without fluidization by the concurrent upflow of air and water.

The use of dual-media filters is now widespread in the United States. Such filters consist of a layer of coarser anthracite coal on top of a layer of finer silica sand. This has better bed utilization because it encourages better penetration of solids. The representative design and operating characteristics of a rapid sand filter of dual-media are summarized

by Letterman (1987). The benefit of dual-media filters is to reduce the rate of headloss development and thus to lengthen the filter run.

The triple-media filters are based on the theory that they have better filter performance than dual-media because an even finer layer of high-density media (garnet or ilmenite) is added as a bottom layer (Conley, 1972, 1965). The bottom layer of finer material would be expected to improve the filtration quality, especially at higher filtration rates. However, this expectation is not conclusive.

Sand-GAC filters have the function of filtration and adsorption of organic matter in water. Most existing GAC filter-adsorbers are retrofitted rapid filters where GAC has replaced part of the sand or anthracite in dual- or triple-media filters. It can be as effective in its filtration function as conventional filter media (either sand or dual-media), provided an appropriate medium size is used. Bablon (1988) reported that 40 cm of GAC with an effective size of 1.2 mm (Effective size was use to describe the 10% size, that is the sieve size that the 10% by weight of the material would penetrate) and 60 cm of crushed sand with an effective size of 0.7 mm are able to remove organic pollution by reducing the assimilable carbonaceous fraction, reducing the chlorine demand, and improving taste and odor. In addition, there is a potential for removing strongly adsorbing compounds.

The problem of sand-GAC filter-adsorbers comes from difficulties in the regeneration of the GAC. The removal of the GAC from the filter-adsorber free of sand, or the separation of the sand after removal, is difficult. Sand causes difficulties in regeneration furnaces. In addition, GAC has a lower density than anthracite, so lower backwash rates are required.

Lower wash rates mean lower hydraulic shear and less effective upflow wash (Pontius, 1990).

Filter media is affected by many factors including backwash, media size, porosity, and water quality. Recent research reports that the headloss through granular media (0.5-1.7mm in size) is sensitive to the porosity of the media bed and the size of the media grains and the headloss was not proportional to the filter rate in a simple way (Chang, 1999). Swertfeger (1999) found that pilot-plant filters containing sand only, typical dual anthracite-sand, and deep dual anthracite-sand media demonstrated similar removal capabilities to remove cyst and oocyst, but turbidity and particle counts demonstrated substantially less removal capability. Kang (1999) concluded that for the anthracite-sand filter, the suspended solids deposition patterns at pH 7 and pH 5 were surface filtration and in-deep filtration, respectively. The anthracite-sand filter exhibited rapid headloss development and suspended solid breakthrough problems at pH 7 and pH5. Fitzpatrick (1998) postulated that the fluidization is affected by the bed packing arrangement which is determined by the previous treatment. Filter media may also be subject to attrition during backwashing which will affect the grain size and voidage.

2.6 Effluent Control Methods of Filter Operation

Filtration processes in water treatment plants are generally hydraulically controlled by one of two methods: constant rate or declining rate filtration. The two operating methods differ primarily in the way the driving force is distributed across the filter media.

2.6.1 Rate Filtration Constant

Constant rate filtration has constant water through rate and it is controlled by an effluent control valve, called a rate-of-flow (ROF) controller. At the start of a filter run, the media are clean and the valve is almost closed to generate headloss, thereby maintaining the flow at the set point. As the media become clogged, the valve opens in proportion to the headloss developed by trapped particles in order to maintain the same flow.

2.6.2 Declining Rate Filtration

Declining rate filtration includes two types of control systems: influent control and effluent control. In both systems, the filters are interconnected by a common influent header with individual inlets entering below the normal low operating water level of the filters. This arrangement causes the water level to be approximately the same in all-operating filters.

In recent years, declining rate filtration has been widely used in many water treatment plants and it has shown good performance. Cornwell (1984) showed that good effluent turbidity was obtained in six declining rate filters. In early studies, Hudson (1959) and Baylis (1959) reviewed declining rate and constant rate controls and concluded that the better water was produced by using declining rate filters in Wyandotte plant and over 50 percent longer filter run was obtained in the Chicago plant. David et. al. (1991) concluded that declining rate filters produce more water for the same system headloss,

the degree being dependent on the amount of turbulent headloss; declining rate filters had a smoother and smaller flow change when a filter was taken out of service for backwashing; and all filter runs were terminated based on headloss, not turbidity breakthrough.

2.7 Monitoring Filter Performance

In evaluating the filter finished water quality, turbidity and particle counts of effluent filter water are the most important parameters.

2.7.1 Turbidity and Turbidimeters

In water treatment plants, turbidity is currently the most widely used indicator of the concentration of particles in water. Turbidity is a measure of the scattering of light by particles suspended in a medium such as water. The deflection or scattering of light is related to a number of optical phenomena that in turn is dependent on the concentration, size, and shape of the particles as well as the wavelength of incident light, the angle of observation, the optical properties of the particles, and the refractive index of the suspended medium (Kerker, 1969). Since turbidity measurements are based on the ratio of incident to scattered light, particulate and dissolved substances that absorb light will decrease the amount of scattered light and may decrease the measured turbidity.

If the turbidity of a dispersion of particles is uniform, it can be correlated with the particle concentration. The higher the concentration of particles, the greater the number of scattering sites. The greater the intensity of scattering, the higher the turbidity. However, in most water treatment applications, particles in a suspension are likely to differ in size, shape, composition, and optical properties. Thus, turbidity is related only qualitatively to particle concentration. Typically, turbidity is measured nephelometrically using a photoelectric detector and is reported in Nephelometric Turbidity Units (NTU).

The turbidimeter design should be most sensitive to particles that are 400 to 600 nm (0.4 to 0.6 µm) in diameter (McEwen, 1998). Turbidimeters are calibrated using standard procedures and standard materials. Turbidity data are collected, reported, and interpreted according to strict industry and regulatory standards.

2.7.2 Particle Count

Particle counting is increasingly becoming a very important tool for water treatment optimization. The technology has the potential to enhance the industry's monitoring and control of water treatment operation due to its sensitivity.

Particle counters are instruments that can measure both the number and the size particles. The instruments most commonly used to analyze water employ light scatter, light obscuration, or electrical resistance measuring systems to analyze one particle at a time (Lewis et al, 1991). The basic components of a particle counter are the sensor and the counter (data processing device). They count and size particles over a range of

approximately 0.5 µm to more than 500 µm. There are three ways in which samples can be analyzed for particle counts: individual sample analysis, on-line sample analysis, and batch/on-line sample analysis.

For on-line sample analysis, a counter unit and a flow control device are needed. The flow control device is able to maintain sensor flow within an acceptable tolerance of the sensor's calibration flow rate. There is no simple "factor" that can be used to correct for sizing and counting errors caused by flow rate deviations from the calibration value. Error introduced into count and sizing data increases with increased deviation from the calibration flow rate (McEwen, 1998).

Despite the interest and apparent acceptance of particle counting technology, there is also widespread concern as to the significance and interpretation of particle count data. In particle counting, each manufacture uses its own techniques to establish the primary calibration of the instruments in the factory. Typically, a calibration curve is generated using polystyrene spheres which are known to be of a certain size. The calibration is therefore done based on sizing of particles. At this time, however, a generally accepted standard for enumerating particles is not available. Therefore, particle counting instruments are not typically calibrated to a count standard in the factory (McEwen, 1998).

2.7.3 Relationship between Particle Counts and Filtered Turbidity

McEwen (1998) conducted a 100-plant survey and concluded that no correlation was found between the filter effluent particle counts and turbidities, and no correlation was found between filtered turbidities and particle log removals. The lack of correlation may be due to the low range of the turbidity data. A general trend of increasing median turbidity values was found both with increasing filtered median particle values and with increasing raw particle concentrations. The AWSI database also suggested that lower turbidities at individual plants would result in lower particle counts and higher log removals of particles. Similar results also were reported by others (Darren, 1994; Hargesheimer and Lwvis, 1995). Darren (1994) reported that although turbidity was the most conservative parameter investigated, turbidity measurements did not reasonably and consistently correlate to particle count measurements and particle counting is a more descriptive and sensitive measure of particle removal efficiency. Hargesheimer (1998) indicated that log removal is not a good indicator of plant performance because it is influenced more by particle counts in source water than by those in finished water.

It has been suggested that laser light obscuration particle counting could be an important tool for water treatment, since it was shown to be more sensitive to change in water quality than turbidimetry (McTigue and Cornwell 1988). But turbidity was, and still is, the regulated parameter to measure particulate removal in a treatment plant.

2.8 Pilot Scale Filter

The pilot-scale filter is a model of a full-scale filter having a much reduced filtering area. The rates of filtration and vertical dimensions should fully duplicate the conditions of a full-scale plant. Generally, a minimum number of three filters is recommended, and they are usually operated in parallel in order to evaluate filter variables in a timely manner because influent quality can vary from test to test.

In order to minimize sidewall effects, a minimum size of the pilot filter column is 3 in. (75 mm) in diameter. In recent years, most pilot filters have been constructed of transparent rigid plastic tables 4 in. (100 mm) or 6 in. (150 mm) in diameter (McEwen, 1998). The pilot filter backwash system should be designed to provide both air and water backwash.

Experience in the water industry (Davis, 1983; Hudson, 1982; Ives, 1966) concluded that a scale-up factor is not required for filtration models and pilot plant performance. Therefore, many parameters may be evaluated in pilot filter studies such as: filtration rates, filter media, quality of effluent, declining-rate versus constant-rate control, and impact of filter wash water recycling. Also, identical geometric similarity between the pilot and full-scale filters eliminate the need for scale-up factors. No significant difference in the pilot and full-scale filter results are expected if the diameter ratio of filter bed/ filter media is greater than 25 (Davis, 1983). Pilot filter data are therefore sufficiently representative that they can provide a direct basis for designing full-scale plants. The principal difference in behavior between small-size pilot filters and full-size units is the tendency for part of the pilot bed to rise upon initiation of the backwash.

Often the bed does not break up of its own volition and mechanical agitation or use of a surface wash is necessary. Because of this concern, adequate freeboard should be provided between the top of the bed and the wash drain outlet (McEwen, 1998).

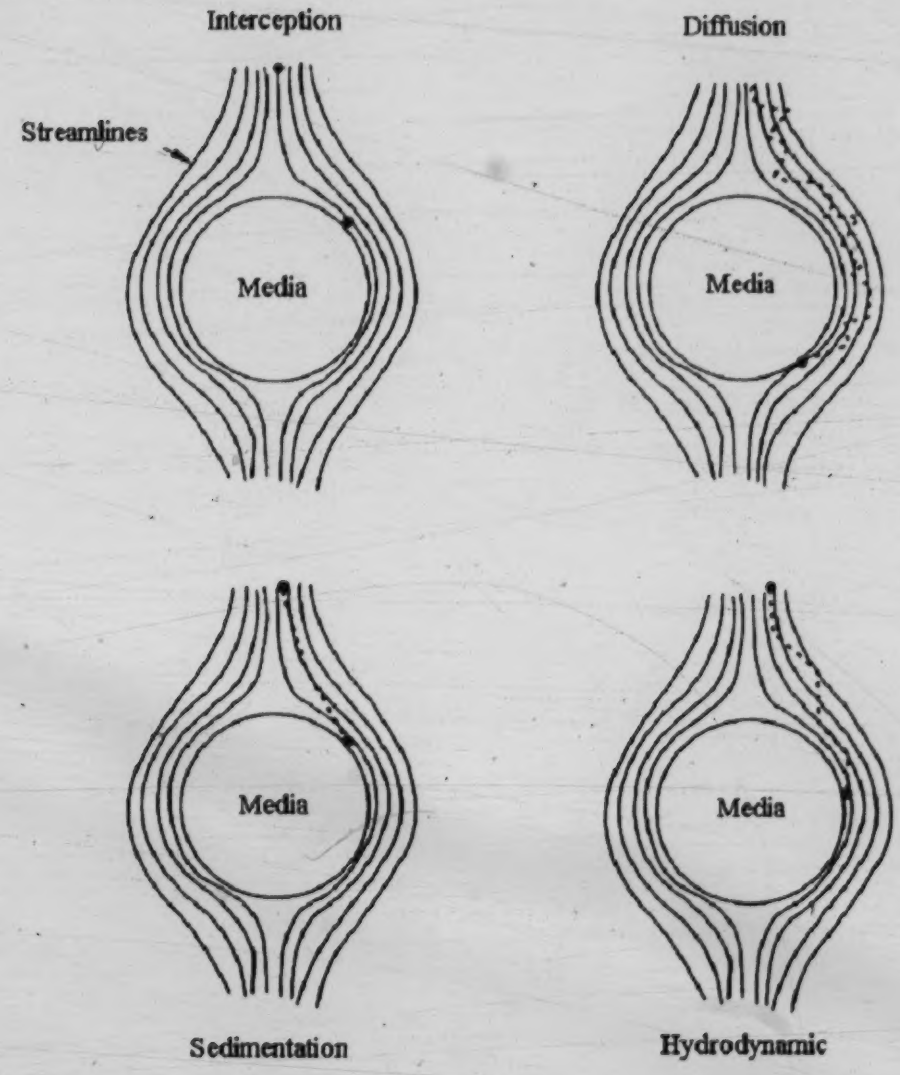


Figure 2.1: Transport Mechanisms (modified from McEwen, 1998)

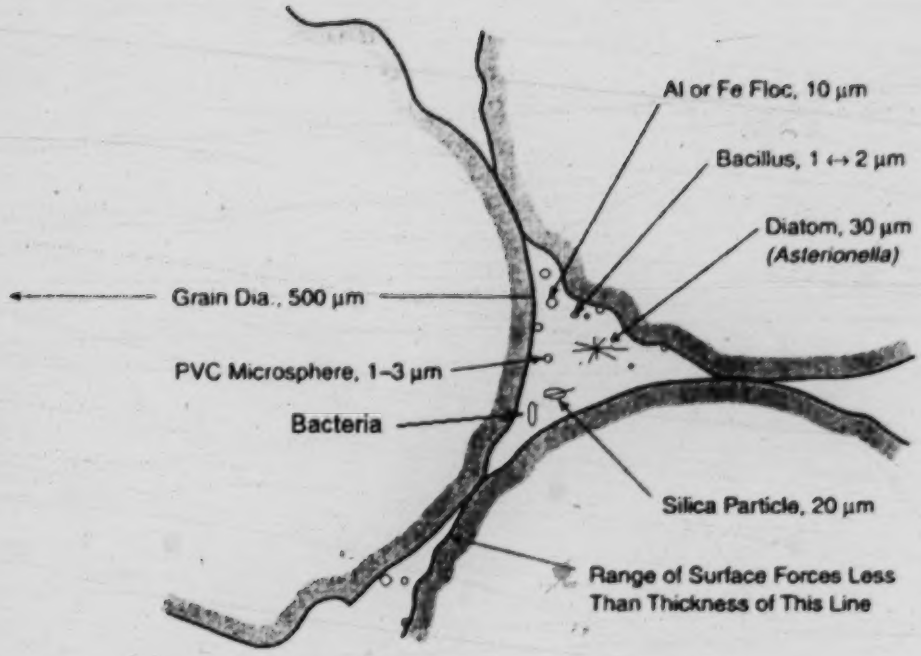


Figure 2.2: Typical Filter Pore (modified from McEwen, 1998)

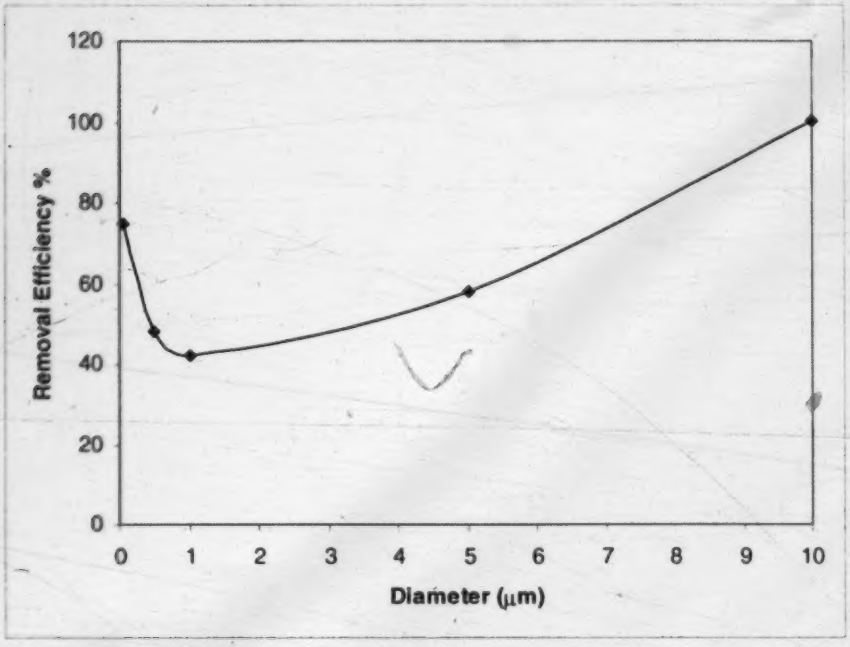


Figure 2.3: Particle Size vs Removal Efficiency (modified from Yao, 1971)

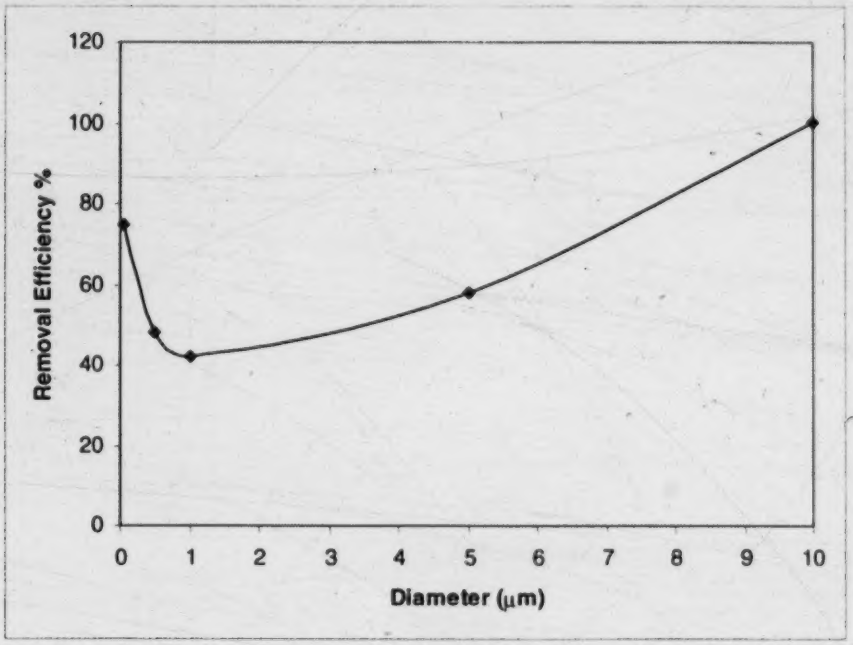


Figure 2.3: Particle Size vs Removal Efficiency (modified from Yao, 1971)

Table 2.1: Organic Coagulants Used in Water Treatment (modified from McEwen, 1998)

Type	Molecular Weight	Uses	Observations
Nonionic Polyacrylamide	10^5-10^7	Coagulant aid, filter aid	Increase floc strength, mostly used As filter aid
Anionic Hydrolyzed Polyacrylamide	10^4-10^7	Coagulant aid, filter aid Sludge conditional	Charge depends on pH
Cationic Poly (DADAMAC) or (DMDAAC)	10^4-10^6	Primary coagulant, color removal Sludge conditional	Used with inorganic coagulant
Cationic Polyamines	10^4-10^7	Primary coagulant Coagulant aid	Charge depends on pH

Table 2.2: Summary of the major characteristics of charge neutralization and interparticle bridging models

Parameter	Charge Neutralization	Interparticle Bridging
Polymer		
Molecular weight	Has no effect on charge neutralization; higher value can lead to bridging	High value is more effect
Charge density	Higher values are more effective	Some charge extends the polymer molecule and makes it more effective
Optimal dose	Near zero charge; dose proportional to total surface charge of particles	Usually not zero charge; dose proportional to particle conc.
Overdose	Leads to charge reversal, restabilization	Leads to excess adsorption and no vacant bridging sites; restabilization
Colloidal Particles		
Concentration	Low-poor flocculation kinetics	Low-poor flocculation kinetics
Solution		
PH	Affects charge density of colloids; affects charge of nonquaternary polymers	Affects charge density of colloids; can affect charge of polymer
Ionic strength	Higher value can aid destabilization	Higher value can aid destabilization and can reduce polymer molecule extension, thus reducing bridging ability

Table 2.3: Typical Properties of Common Filter Media for Granular-Bed Filters (Pontius, 1990)

	Silica Sand	Anthracite Coal	GAC	Garnet	Ilmenite
Grain density, g/cm^3	2.65	1.45-1.73	1.3-1.5	3.6-4.2	4.2-4.6
Loose-bed porosity	0.42-0.47	0.56-0.6	0.5	0.45-0.55	no
Sphericity	0.7-0.8	0.46-0.6	0.75	0.60	no

Table 2.4: Typical Grain Sizes for Different Application (Pontius, 1990)

	Effective size, mm	Total depth, m
Common U.S. Practice after Coagulation and Settling		
1. Sand alone	0.45-0.55	0.6-0.7
2. Dual media	0.9-1.1	0.6-0.9
Add anthracite (0.1-0.7 m of bed)		
3. Triple media	0.2-0.3	0.7-1.0
Add garnet (0.1m)		

3 Methods and Apparatus

3.1 Pilot Plant Setup

3.1.1 Pilot Plant Description

Six clean PVC columns, 150mm in diameter, were used as the filters. Four different media were used as filter media with the depth of 70 to 75 cm. Five piezometer stop valves were installed in each column to measure headloss. Table 3.1 shows the media in each filter.

The pilot plant was equipped with particle counters under the control of a computer. Four Met One model PCX particle count sensors were used during the remaining testing program, thereby allowing one influent and three filtered effluent particle counts to be monitored simultaneously.

Influent and filtered water turbidities were measured with 1720D on-line turbidimeters. The influent water pH value was monitored using an on-line pH meter.

Each filter was equipped with two flow meters and valves. One was used for controlling the influent flow rate and the other was used to measure the change of effluent flow rate. Figure 3.1 shows a view of the pilot plant filters. Figure 3.2 shows a schematic of the pilot plant filters

Polymer is feed to a mixing tank, then it is mixed with the influent water. The mixing tank was equipped with a variable speed mixing motor. Details of the mixing tank can be found in Appendix.

3.1.2 Pilot Plant Operation

In each run, the filtration system was operated under a constant influent flow rate (9 m/hr.) and a declining effluent flow rate (at the beginning, the flow rate is 7.5 m/hr.). Three filters were run in parallel. One was used as a control and the other two were fed with polymer solutions. Normally, the mixing rate in the polymer mixing tank was set at G values 200 – 2000 s^{-1}. The turbidity, particle count, and pH were continuously monitored and recorded every five minutes by a computer. The headloss and declining effluent rate were recorded about every 24 hours.

After each run, the filters were first backwashed using air scour, then with water. The detailed procedures of filter operation and backwash are included in Appendix I.

3.2 Pilot Plant Water Quality Monitor

Turbidimeter, particle counter and pH meter were used to monitor the influent and filtered water quality in this study. The following gives a brief description of these instruments.

3.2.1 Turbidimeter

1720D process turbidimeter was used to on-line monitor the turbidity of influent and effluent water. The basic 1720D turbidimeter system is shown in Figures 3.3 and 3.4.

The 1720D turbidimeter is a continuous-reading nephlometric turbidimeter designed for low-range turbidity monitoring. This process turbidimeter consists of a 1720D head assembly, 1720D body, and PS 1201 power supply and is capable of measuring turbidity from 0.001 to 100.0 NTU (HACH Company Manual, 1998).

Turbidity is measured in the 1720D turbidimeter by directing a strong beam of light from the sensor head assembly down into the sample in the turbidimeter body. Light scattered at 90^0 by suspended particles in the sample is detected by the submerged photocell. The amount of light scattered is proportional to the turbidity of the sample. If the turbidity of the sample is negligible, little light will be scattered and detected by the photocell and the turbidity reading will be low. High turbidity, on the other hand, will cause a high level of light scattering and result in a high reading (HACH Company Manual, 1998).

The sample enters the turbidimeter body and flows through the baffle network of the bubble trap. The flow allows bubbles to either cling to surfaces of the baffle system or rise to the surface and vent to the atmosphere. After traveling through the bubble trap, the sample enters the center column of the turbidimeter body, rises into the measuring chamber and spills over the weir into the drain port. A reading is taken every three seconds.

The calibration method of this turbidimeter is based on formazin, the primary turbidity reference standard adopted by the *APHA Standard Methods for the Examination of Water and Wastewater* and the U.S. Environmental Protection Agency (EPA). A more detailed calibration procedure is provided in Appendix II.

3.2.2 Particle Counter

Met One's laser-diode-based particle counting sensors are specifically designed for drinking water applications. Water is directed into the sensor and funneled through the sensor generates a signal corresponding to its size. Each sensor comes with a calibration curve showing the signal response versus size of each sensor. Met One uses NIST-traceable spheres of known size to calibrate each sensor. This information is stored in the memory of the sensor, and is used to separate the particle counts into the proper size category.

When a sample including small particles enters the measuring system of a particle count, particles are counted and sized directly using a laser beam. Each particle presented in the water will interrupt the laser beam, which causes the light-scattering. The scattering light is collected by the optical system of the photodetector assembly. The flash of light striking the detector creates an electrical pulse, the amplitude of which is related to the size of the particle. The numbers of particles are also counted. The laser light beam sweeps through the sample at a constant speed for a set period of time, thereby allowing the instrument to record the number of particles in a predetermined volume (Cornwell, D.A, 1991). Figure 3.5 shows the flow controller for the system.

Typically, the smallest particle counted is down to 2 microns, and the largest is up to 750 microns. The flow rate is 100 mL/minute. For the cleaning procedures for the sensor, refer to Appendix II.

3.3 Experimental Design

In order to accomplish the objectives previously set up for this study, the experiments were done in the following four stages:

First, six types of polymers were selected and tested in pilot-plant filters according to early experiment data (Zhu, 1994). The names and characteristics of these six polymers are:

Percol LT – 24: powder, polyacrylamide, medium-molecular-weight, cationic, low-charge-density.

Percol LT – 22: powder, high molecular weight, medium-charge-density, cationic.

Percol LT – 20: powder, high molecular weight, non-ionic.

Percol LT – 7996: liquid, pDADMAC, low-molecular-weight, cationic, high-charge-density.

Nalcolyte 8100: liquid, polyamine, cationic.

POL – E – Z 652: emulsion, polyacrylamide, high-molecular-weight, non-ionic.

Second, testing to find the best dosages of polymers that decrease the effluent turbidities and particle counts.

Third, adjusting the mixing intensity of polymer tanks to optimize the pilot-plant operation. Generally, the most important factors affecting the performance of the filtration include filtrate rate, mixing intensity, and polymer dosage. Since the filtration rate was set up based on demands of the full-scale plant, no further study was needed at this time. The dosage was also studied in the second stage. So only the effect of mixing intensity on filtration was investigated in this study. The mixing intensity varied from 200 s^{-1} to 2000 s^{-1} in the tests.

Finally, comparing the performance of various media to further improve the effluent quality under the conditions of optimized polymer aided filtration.

It must be emphasized that all the tests were conducted by varying one operating parameter while holding the others constant. For the preparation of polymer solution, refer to Appendix III.

The polymer concentrations mentioned in this study are those at the exit from the mixing tank.

Table 3.1: The media and size of each filter

	Filter1	Filter2	Filter3	Filter4	Filter5	Filter6
Filter Media	Sand	Anthracite Sand	Sand	GAC Sand	Sand	Fine Sand
(mm)	0.5	1.0-1.1, 0.5	0.5	0.8-0.9 0.5	0.5	0.35
Depth (cm)	75	35 40	75	35 40	75	75
Total Depth (cm)	75	75	75	75	75	75

Figure 3.1: A View of Pilot Plant Filters

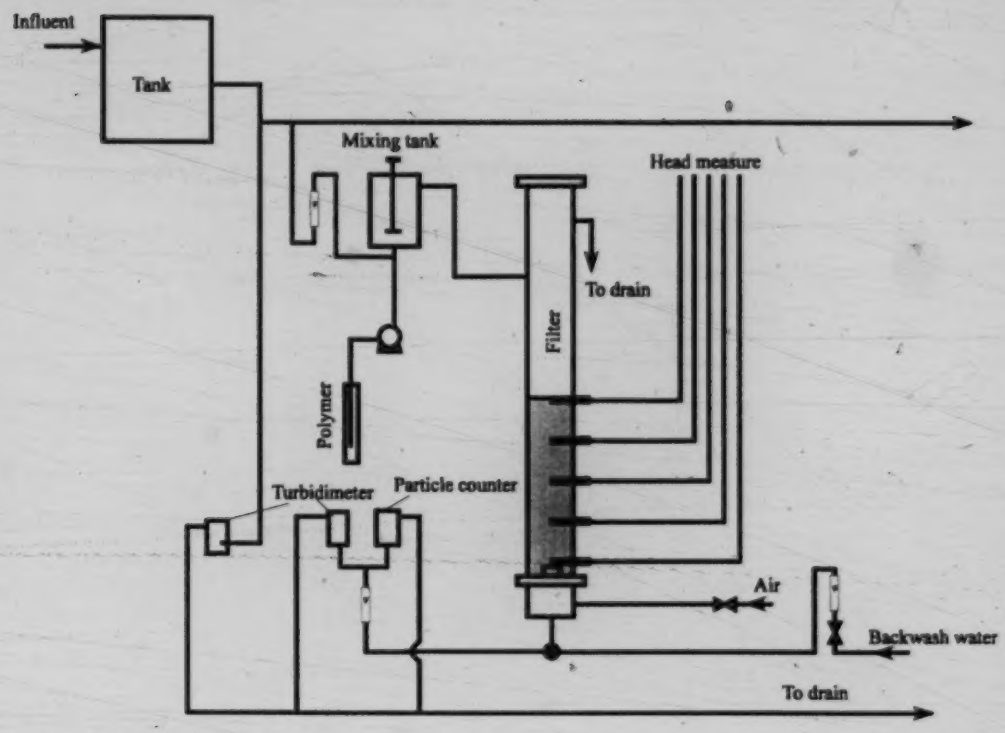


Figure 3.2: A Schematic of Pilot Plant Filters

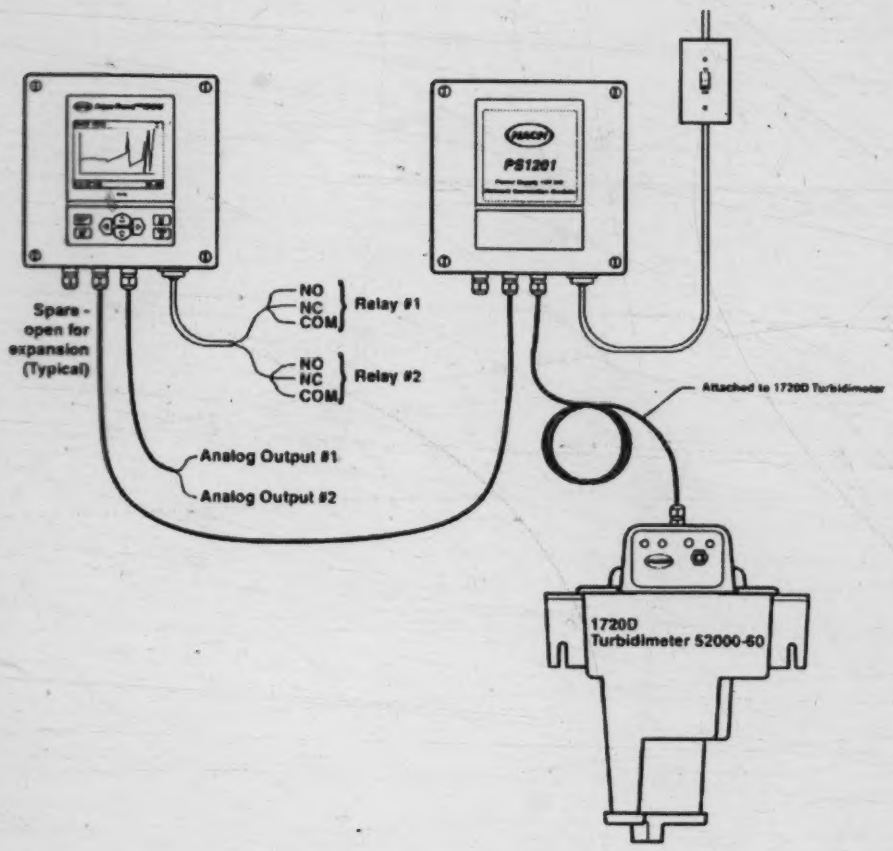


Figure 3.3: Basic 1720D Turbidimeter System (modified from 1720D manual)

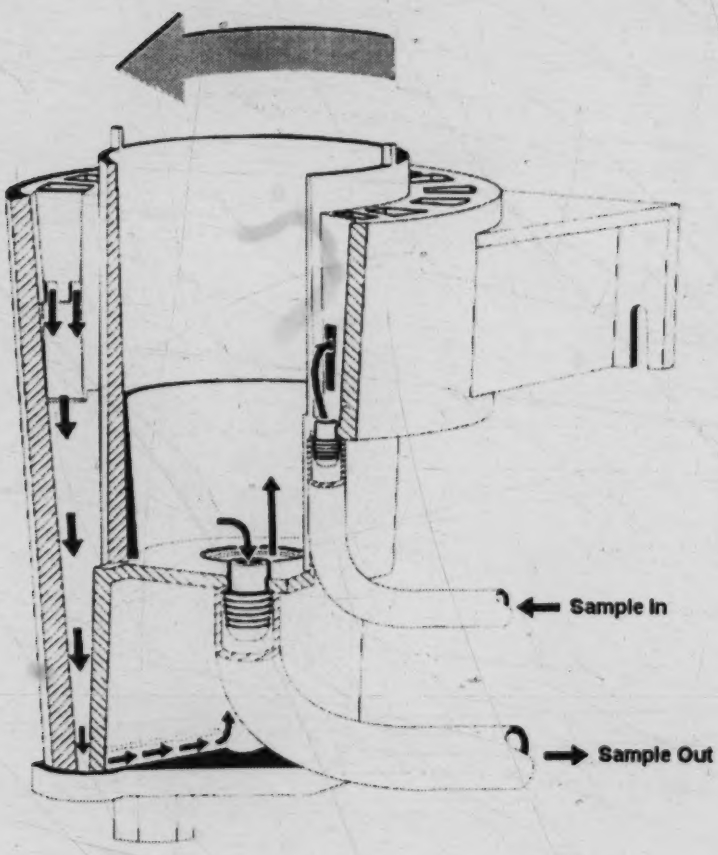


Figure 3.4: Sample Flow Path Through the Turbidimeter System (modified from 1720D manual)

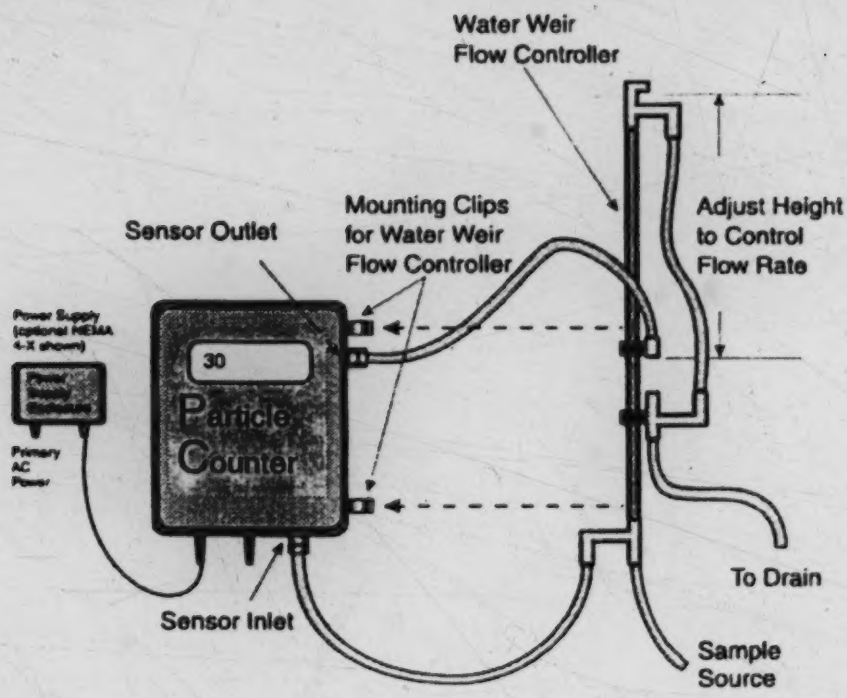


Figure 3.5: Particle Counter connecting System (modified from PCX manual)

4 Results and Discussion

4.1 Comparison of Full Scale Filtration with Pilot Plant Filtration

Pilot plant filters are used to evaluate and predict the performance of the full scale plant in response to the changes of water quality or operating conditions. At the Rossdale water treatment plant in Edmonton, Alberta, Canada, the pilot plant filters were designed according to the full scale criteria, for example, using the same crushed quartz sand in size and depth as filter media, using similar backwashing conditions, similar effluent starting flowrate. This pilot plant experiment was designed to simulate the full scale operation to match the full scale operation and can represent the filtration performance of the full scale filters.

The primary goal of the research was to investigate the impact of removing softening from the treatment process. Initial results indicated that particle counts increase using unsoftened water. As a result it was indicated to investigate filter optimization techniques, mainly polymer addition and different media to improve particle counts for unsoftened water.

The first step in the investigation was to assess the ability of the pilot plant to represent full scale condition. Softened water was run through the pilot plant and compared to similar water at full scale. Figure 4.1 shows the alteration of effluent water quality with

the filter run time for softened water filtration in a full-scale filter with polymer addition in the Rossdale water treatment plant. The full-scale filtration produced water with low effluent particle count and turbidities. The filter run time was about 50 hours and the effluent water quality was consistent. In run periods, the influent water had low particle counts from 4600 to 5700 particle/mL (>2 μm) and medium turbidities from 3.8 to 4.2 NTU. The pH value was about 8.

Figure 4.2 represents the pilot plant filtration performance for softened water filtration without polymer addition. The result showed that the effluent particle counts and turbidities for three filters had the same tendency as the full-scale filtration with polymer. The filter run time was about 30 hours, but this filter run had a longer ripening time than that of full-scale filtration. The reason probably is that no big enough flocs were formed because no polymer was added in this run.

According to the analysis above, it was found that the pilot plant filters matched the full-scale filters well. So, the filtration performance of the full scale filters can be used from the pilot plant experiment which will provide guidance for a full scale improvement in response to the change of influent water quality.

4.2 The Comparison of Unsoftened Water with Softened Water in Pilot Filters

As aforementioned, if the softening process at the Rossdale water treatment plant was stopped, the influent water quality change would possibly deteriorate the effluent water

quality of filtration. In order to improve the effluent water to meet the effluent water standards, some improvement in filtration process will be required. How to and what should be changed to improve the filtration process are the questions. The following experiments were designed to answer the questions. The results of different water filtration (softened and unsoftened water) were compared and some suggestions were obtained.

Figures 4.2 and 4.3 show the effluent particle counts and turbidities of softened water and unsoftened water respectively. The experimental results showed that the effluent particle counts were less than 50 particles / mL (>2 μm) and the turbidities were less than 0.1 NTU in the best filter run time for softened water filtration. The filter run time lasted about 30 hours. The breakthrough comes from the filter media saturation.

For the unsoftened water (Figure 4.3) the effluent particle counts were from 30 to 250 particle/mL (>2 μm) and varied significantly among the three filters. The experiment was repeated and similar results were obtained: all three filters were not performing consistently although each filter performed similarly in the two runs. The effluent turbidities were less than 0.1 NTU and the best filter run time was about 21 hours with a very short ripening time. The breakthrough comes from the headloss of filters.

From the above results and analysis, it was found that worse effluent water quality, shorter filter run time, and more inconsistent performance (all three filters are not performing consistently) were obtained in unsoftened water filtration comparing with softened water filtration. The above results predict that the current filters in the Rossdale water treatment plant would have trouble with unsoftened water. There are a lot of

improvements and adjustments required to produce drinking water that meets the WTP effluent water standards.

The curves in Figure 4.3 (a) show that particle counts were high for the first half day (600-800 particle/mL), but dropped off as the effluent flowrate decreased (all the filters were less than 1/2 their original flow within the 24 hour run). The result indicated that the influent particles of unsoftened water either have smaller sizes than those of softened water or the surface chemistry of the particles reduce their ability to attach to the filter media. The phenomenon can be explained by the filtration mechanism: particles that lie on streamlines close to the grain surfaces may touch the grains and this is called interception. The larger the particle size, the greater the probability of the particle touching the grain. Very small particles (< 1μm) are affected by Brownian motion, which includes random movements, although diffusion moves particles down concentration gradients. This diffusion action creates movement that may lead to a particle touching a grain. The smaller the particle, the greater the diffusive movement leading to contact with the grain. But a practical consequence of this minimum in removal efficiency is that particle flocculation (perikinetic) of clays from 0.1 to 1 μm in size is detrimental to filtration. The flocculation must proceed further (orthokinetic) to produce flocs about 10 μm in size in order to improve filtration (McEwen, 1998). Another explanation for the phenomenon is hydraulic shear produced by the water flowing in the filter pores. The pilot plant filters at the Rossdale water treatment plant uses the declining effluent flowrate control. That means the effluent flowrate decreases during the filter run. At the beginning of filtration, the density of the filter bed is loose and the porosity is large. This will decrease the probability that the smaller particles attach to the surface of filter media.

In a filter, there exists a very delicate balance between the hydraulic shears and the particle adhesive force to the filter media. The shear force increases if the local flow rate increases. If the hydraulic shear force is greater than the particle adhesive force, it tends to dislodge previously deposited material from filter media, and to prevent deposition of material presently being applied in the filter.

From the analysis of the above experimental results, the following factors should be considered: Selection of polymers to increase the particle flocs to improve the efficiency of filtration. The particles that enter the filters are negatively or uncharged, so cationic and non-ionic polymers will be selected.

(1) The optimization of polymer types and dosages according to the following parameters: effluent water quality (particle counts and turbidities), headloss, and the declining rate of effluent flowrate of the filter. At the same time, the mixing intensity will be investigated to find a better operating condition to increase the efficiency of polymers,

(2) Test of filter media to improve the efficiency of filtration and extend the filter run time.

4.3 pH Adjustment

The pH value of influent water affects the filtration process. For unsoftened water, the pH value generally is less than 8 and should be around 7. The pH effects the particle charges

and their floc sizes in sedimentation process, hence it also affects the filtration process by the changes of particle-medium adsorption characteristics. So, it is necessary to investigate the effect of pH on the filtration process, then to adjust the pH value using on-line CO_2 addition to stabilize the influent water pH value to decrease the effect of pH on filtration operation.

Figure 4.4 shows the results of pH values on effluent water quality without the use of polymers. There were almost no differences in the particle counts and turbidities when the pH values changed from 7.1 to 7.7 in the best filter run time although the influent water varied. However, the pH values affected the filter run time. The higher the pH values, the shorter the filter run time. Consequently, the lower pH values are preferred.

4.4 Selection of Polymer as Filter Aids

From the screening tests (Zhu, 1994) and some other experiments (E.L. Smith water plant, unsoftened water filtration), six types of polymers were selected as filter aids. The characteristics of these polymers were outlined in Chapter 3.

The parameters, effluent particle count and turbidity, were used to evaluate the effects of polymers as filter aids on filtration performance. They were also tested to select the most suitable polymers for the treatment of unsoftened water. The experiments were designed as follows: Filters 1 and 5 were arranging to test different polymer dosages. Filter 3 was used as a control. The use of Filter 3 as a control was to account for the influent quality variation and to eliminate the possible interference of polymer residues within the filter

media. Some experiments were repeated to confirm the experimental results. The selected polymers and their dosages are shown in Table 4.1. The experimental results are presented in Figure 4.5 to Figure 4.10.

Figure 4.5 to Figure 4.10 show the relationship of effluent particle counts and turbidities as a function of filter run time, indicating that the filter run time for all polymers tested was less than 24 hours. That means the unsoftened water filtration had short filter run time in the crushed quartz sand medium filters regardless of whether polymer aids were used or not. Almost all the effluent turbidities were about 0.06 NTU with the use of polymers, regardless of the fluctuations in influent turbidities (about 4 to 5 NTU). However, the effluent particle counts varied markedly among the different types of polymers.

For Nalcolyte 8100 polymer (Figure 4.5), the higher dosage (1.0 mg/L) had the better filtration performance in comparison with the lower dosage (0.05 mg/L) or no polymer. The effluent particle counts were less than 20 particle/mL (>2 μm). The counts were far less than those of no polymer-aid filtration. The effluent turbidity was about 0.06 NTU, greater than those of no polymer aid filtration (by about 0.04 NTU), but it was still less than 0.1 NTU (the newest effluent guide). It was observed that by using Nalcolyte 8100 polymer, the filter run time was about 21 hours. However, the filter run time was about 15 hours without polymer addition.

When Percol LT 24 polymer (Figure 4.6) was used as the filter aid, it not only lowered effluent particle counts, less than 50 particle /mL (> 2μm), but also lowered effluent turbidities (about 0.06 NTU) in comparison with those of no polymer aid filtration. The

higher dosage (0.01 mg/L) showed better filtration performance than the lower dosage (0.001 mg/L) and the filter run time was about 23 hours when the higher dosage of polymer was added.

Figure 4.7 shows the performance of POL E-Z 652 polymer as a filter aid. The effluent particle counts and turbidities were lower (about 50 particle /mL, and 0.06 NTU), but the effluent turbidity fluctuated and the filter run time was shorter, at about 18 hours.

Lower dosage (0.1 mg/L) Percol LT 7996 polymer used as a filter aid (Figure 4.8) had the similar filtration performance in comparison with the no polymer aid filtration. Moreover, the higher dosage (0.25 mg/L) gave even worse effluent water quality.

Percol LT 22 polymer (Figure 4.9) and Percol LT 7996 polymers performed similarly. A worse effluent water quality was obtained when Percol LT 20 polymer (Figure 4.10) was used as the filter aid, compared to no polymer aid filtration.

From the observation above, it seems that the cationic polymers (such as Nalcolyte 8100 and Percol LT 24) used as filter aids had equal or better filtration performance in comparison with the non-ionic polymers such as POL E-Z 652, and Percol LT 22. Similar results were reported by Stump and Novak (1979). The medium molecular weight polymers had slightly better filtration performance than the higher molecular weight polymers. However the change of density of polymers seemed to have little effect on the filtrate water quality.

Nalcolyte 8100 and Percol LT 24 polymers were selected for optimization experiments due to their better filtration performance. POL E-Z 652 polymer was also considered for

the optimization experiment because of its better filtration performance although the effluent turbidity fluctuated.

Considering the fact that the charge density of polymers seemed to have little effect on the filtrate water quality, the improvement of effluent water quality using polymer aid filtration seemed to favor the mechanism of the bridging between the polymer and particles instead of the mechanism of charge neutralization.

Usually, the interparticle bridging model was used to explain the interaction between particles and high molecular weight ($> 10^6$) polymers. However, it was also applied to low molecular weight polymers (Habibian and O'Melia, 1975; Yeh and Ghosh, 1981). In bridging mechanism, when a polymer molecular and a suspended particle come in contact, some of the chemical groups of the polymer will adsorb onto the surface of the suspended particle at one or more adsorption sites. At the same time, some of the polymer segments will extend into the solution phase. These extended segments may attach to other suspended particles with vacant adsorption sites, forming a polymer-particle complex with the polymer as a bridge (Zhu, 1995). The particles are thus bound into a floc that can grow to a size limited by the shear forces in the system and the amount of polymer initially adsorbed upon the surfaces of the particles. In bridging, the polymer molecular weight would become more important than the polymer charge density. For a given type of polymer, the higher the molecular weight, the more effective the particle removal because the large number of binding hydrogen or other bounds make the stronger binding to both filter media and colloids. However, excessively high molecular weight might cause the increase in the headloss and the formation of large

flocs deposited at the surface of filter (Habibian and O'Melia, 1975; Leu and Ghosh, 1988).

4.5 Optimization of Polymer Filtration

In filter operation, many factors affect the polymer performance and the filtration efficiency. The factors include the filtration rate, mixing intensity and polymer dosage. Since the filtration rate was set based on the needs of the full-scale plant, no further study was performed. Therefore, mixing intensity in polymer tanks, headloss development in filters, and effluent flowrate decline were studied to choose the best polymers and filter operating conditions. The tests were conducted by changing one operating parameter while holding the others constant.

4.5.1 Mixing Intensity in Polymer Tanks

In all of the experimental runs, the optimal polymer dosages were selected based on the above experiment result shown in Table 4.1.

Figures 4.11 to 4.13 present the effect of mixing rate on the effluent water quality (particle counts and turbidities) using three types of polymers, Nalcolyte 8100, POL E-Z 652 polymers, and Percol LT 24. With the increase of mixing rate in polymer tanks from 200 s^{-1} to 2000 s^{-1}, the following results were obtained:

(1) effluent particle counts and turbidities were lower

(2) fluctuation of effluent water quality was less, and

(3) filter run times were longer and ripening times were shorter.

It is well known that mixing is an important process parameter for chemical addition for particle destabilization followed by particle aggregation. A high intensity of mixing during the very first seconds after chemical addition is crucial for charge neutralization and the polymer-particle bridging formation. It not only affects the adsorpted rate between colloid particles and the polymer, but also minimizes or eliminates local overdosing of the polymer. So the appropriate mixing will give the optimum contact between particles and polymer adsorption sites as well as allow lower chemical dose. Hahn and Stumm (1968) reported that the formation of hydrocomplex species and their adsorption on the particle surface take place extremely quickly, within microseconds for monomeric species and within one second if polymeric species are involved.

It is known that filtration is a non-steady fluid flow process in which the trapping alters the flow field. When polymer is added, it is first mixed with the particles before entering the filter bed. If inadequate mixing were used, it would cause the local overdose to form the big local flocs of particle-polymer. At the same time, some particles would not be aggregated by the polymer due to the uneven distribution of the polymer. When the liquid including the particle-polymer flocs and free particles enters the filter bed, the adsorption sites of media would adsorb the large particle-polymer flocs and the small free particles to form an uneven distribution in pore media of filter bed. The larger flocs in the filter bed will cause the rapid clogging in the upper level of filter bed. It would decrease the

effective use of bed depth, then result in the earlier breakthrough and shorter filter run time. It was observed in some experimental runs that a thin layer on top of the filter (2-3 mm thick) was formed when inadequate mixing rate was used. This phenomenon also supports the explanation above.

Figure 4.13 shows the correlation of various mixing rates (G values, low $200s^{-1}$, medium $1300s^{-1}$, and high $2000s^{-1}$) and the effluent water quality when 0.01 mg/L Percol LT 24 polymer was used. Predictably, the result indicated that the faster the mixing rate, the better the effluent water quality and the longer the filter run time. The effluent particle counts had no big difference when using medium mixing rate or using high mixing rate. However, the high mixing rate made the filter run time extend about 3 times longer when compared to the medium mixing rate. So the higher mixing rate in polymer tanks plays an important role in improving filtration performance, especially in prolonging the filter run time. Due to the limitation of experimental instrument, $2000s^{-1}$ of G value mixing was the maximum. But this does not mean that the much higher mixing rates, the better effluent water quality will be. An excessive mixing rate may cause flocs breakup to decrease the efficiency of polymers and increase the operation cost due to excess power consumption.

4.5.2 The Development of Headloss and Declining Effluent Flowrate

Figures 4.14 to 4.16 show the relationship of effluent flowrate and filter run time at different mixing rates when using three types of polymers. The results indicated that the effluent flowrate decreased with the decrease of mixing rate and the prolongation of filter run time. The reduction of effluent flowrate had the same tendency among three types of

polymers. Comparing the Figures, it was obvious that Percol LT 24 polymer at G value $2000s^{-1}$ seemed to give a longer filter run time and a smaller reduction of effluent flowrate. When the filters ran for about 20 hours, the effluent flowrate of the filters in Nalcolyte 8100 and POL E-Z 652 polymer aid filtration at G value $2000s^{-1}$ was about 1.0 L/min, whereas the effluent flowrate of Percol LT 24 polymer filter was around 2.25 L/min (compared to the control filter flowrate of 2.5 L/min).

The development of headloss as a function of filter run time for three types of polymers at different mixing rate are shown in Figures 4.17 to 4.19. The results showed that the headloss development linearly increases with the filter run without polymer aid filtration. But the headloss in polymer aid filtration developed faster with the prolongation of filter run time. The lower the mixing rate, the faster the headloss development.

The decrease of flowrate in a filter and the development of headloss are as important as filtration quality in evaluating the filtration performance. The flowrate determines the amount of water production, and the development of headloss restricts the filter run length, determines when the filter needs to be cleaned, and controls the net unit water production in most filter runs. Both parameters are directly related to the frequency of filter backwash and the operating cost. The data obtained suggest that addition of medium molecular weight Percol LT 24 polymer results in better filtration performance (lower effluent turbidity, longer filter run time, as well as slower development of headloss and slower reduction of effluent flowrate) in comparison with the addition of high molecular weight polymer such as POL E-Z 652 polymer. The development of headloss and decline of effluent flowrate in the filter tend to occur at a greater rate with the use of polymers compared to without the use of polymers. The phenomena might be explained by the

formation of stronger and larger flocs when polymers are used as filter aids. The higher the molecular weight of polymers, the larger the flocs. When the larger flocs enter the filter, they affect the distribution of headloss in a filter. The development of headloss is also dependent on molecular weight of polymers and mixing intensity. With the prolongation of the filter run time, more flocs accumulate in the media. The larger the flocs, the faster the headloss development. Thus, selecting polymer with a proper molecular weight is an important step in unsoftened water filtration.

4.5.3 Polymer Dosage

Based on the above experimental results, the Percol LT 24 polymer was selected as a representative for the study of polymer dosage because it performed the best. The constant operating conditions are: mixing rate at G value 2000s^{-1} in polymer tanks; influent flowrate at 3 L/min (9 m/hr); effluent flowrate at 2.5 L/min (7.5 m/hr) in each run starting with 0.5 mm crushed quartz sand as filter media at 75 cm in depth. Filter 3 was used as a control without polymer addition. Filters 1 and 5 were used with the addition of different polymer dosage. The results are shown in Figures 4.20 to 4.22.

During that experimental period, the influent water quality had higher particle counts from 13,000 to 18,000 particle/mL (>2 µm), medium or lower turbidities around 2 to 4 NTU, and low pH value about 6.5. Due to the seasonal water quality variation, powder activated carbon (PAC) was added prior to filtration to remove the taste, color, and more particles.

Figure 4.20 indicates that when the polymer dosage increased from 0.001 mg/L to 0.01 mg/L, the effluent particle counts and turbidities decreased from about 125 particles/ml to less than 50 particles/ml (>2 μm) and the turbidities from 0.05 NTU to 0.03 NTU. However, the filter run time was shortened from about 90 hours to 60 hours.

The decrease of effluent flowrate and increase of headloss in the filter were shown in Figures 4.21 and 4.22, respectively. The results indicate that the effluent flowrate was becoming slower with the increase of Percol LT 24 polymer dosage and the development of headloss was getting faster with the increase of polymer dosage.

From the analysis of Figures 4.20 to 4.22, a conclusion can be drawn that the dosage 0.005 mg/L of Percol LT 24 polymer as filter aid for water filtration was the optimal dosage because it gave the better effluent water, the longer filter run time, and the less change of headloss and effluent flowrate. It must be pointed out that all the experiments with PAC (Powder Activated Carbon) addition exhibited better effluent water quality than the normal experiments without PAC addition no matter whether the polymers were added or not. The best dosage is therefore also dependent on the influent water quality. As indicated by McEwen (1998), the optimum dosage is directly related to the concentration of particles to be destabilized by bridging. That is, the amount of polymer needed to form particle-polymer-particle bridging is dependent on the number of particles.

It also must be mentioned that in this pilot plant study, the influent water quality could not be controlled. The optimization of polymer dosages is affected by PAC addition.

Thus, it is necessary to further compare the impact of influent water quality on polymer dosages with or without PAC addition.

4.6 Powder Activated Carbon Impact on Filtration Performance

In this stage, the experiments were designed to investigate the impact of PAC on filtration performance without PAC addition before filtration in order to compare with the filtration performance discussed above. The influent water quality has the following characteristics:

(1) low particle counts from 3000 to 5000 particle/mL (>2 μm)

(2) low turbidities about 0.5 NTU, from 0.4 to 1.2 NTU

(3) pH value 6.7 to 7.1

Figures 4.23 to 4.25 show the performance of filters without polymer addition, indicating that all three filters (1, 3, and 5) with 0.5 mm crushed quartz sand were performing consistently. The effluent particle counts were about 350 particles /mL (>2 μm). The curves of effluent particle counts showed a great fluctuation. It was hard to define the filter run time from these curves. However, the effluent turbidities kept consistent, about 0.06 to 0.07 NTU. Figures 4.24 and 4.25 also indicated that the reduction of effluent flowrate was accompanied with the increase of headloss. After 20 hour run, the headloss and the reduction of effluent flowrate changed a lot. Comparing with Figures 4.20 to 4.22, it was found that the filter run time was about 90 hours with PAC addition prior to

filtration, more than 3 times longer than that of without PAC addition (no polymer aid added). The effluent water quality was also better with the use of PAC.

Figure 4.26 shows the effluent water particle counts and turbidities with the use of Percol LT 24 polymer as a filter aid at different dosages. The result indicated that with the increase of polymer dosages, the effluent particle counts and turbidities were decreased, the filter run time was shortened, and the fluctuation of effluent water quality was decreased. The filtration performance of Percol LT 24 polymer as a filter aid without PAC addition before filtration was much worse than with the use of PAC, as shown in Figure 4.20.

Generally, powder activated carbon (PAC) is added immediately following the flash-mixing stage. The flocculation equipment is then used to enable the PAC to be in contact with the water being treated. It is used seasonally due to the raw water quality variation. It is expensive but powerful for eliminating trace amount of organic pollutants. When PAC is added, it forms very effective nuclei for flocculation. The floc is able to grow much more easily around the specks of PAC. It increases in size and falls to the bottom more quickly (McEwen, 1998).

The above comparison indicated that PAC addition prior to filtration had a great improvement for water filtration, especially in the runoff season. In that period, the influent water quality seemed to have little relation with polymer dosages. Although the best type of polymer was used, the effluent water quality after filtration process still had higher particle counts. So the PAC addition is absolutely necessary to further improve the drinking water quality during certain times of the year.

4.7 Evaluation of Filter Media

In drinking water filtration, the selection and evaluation of filter media are quite important aspects for improvement of filtration performance. Because filtration is the final physical process for particle removal in a conventional water treatment plant, the upgrading of the filtration process will be an important aspect in improving effluent water quality to meet the drinking water standards.

The evaluation of filter media includes many aspects such as the origins and shapes of filter media, the size of media, the depth and porosity of a filter bed, etc. Due to the restrictions in changing the existing pilot plant filters, the optimization of size and filter bed porosity were not conducted. The filter bed depth built in the pilot plant matched that of full scale filters at Rossdale water treatment plant. Consequently, only the selection of filter media types was studied in this thesis. The selection of filter media should result in: (1) reduction of effluent particle counts and turbidities to improve water quality to satisfy more stringent licensing requirements and guidelines; (2) consistent operation; (3) proper filter run length and less headloss; and (4) being able to withstand and sudden influent variation.

In this experimental stage, the influent water quality has the following characteristics:

(1) particle count: 12,000 to 15,000 particle/mL (> 2 μm/mL)

(2) Turbidity: 12 to 28 NTU with 15 NTU in average

(3) pH value: 5.2 to 6.5, at most time in the range of 5.8 to 6.1

The selected filter media in this pilot plant are listed in Table 3.1. The performance of filter media was compared to that of the 0.5 mm crushed quartz sand.

4.7.1 The Comparison of Various Media without Polymer Addition

The effluent particle counts and turbidities were shown in Figures 4.27 and 4.28. The effluent water quality from Filters 2 (anthracite-sand) and 4 (GAC-sand) were worse than that from the Filter 5 (control). The Filter 6 gave the best effluent particle counts (about 30 particle/mL), but the worst effluent turbidities (about 0.45 NTU).

The particle counts were higher in dual-media columns in comparison with the mono-medium column without polymer addition. One possible explanation is that the filter media (anthticate and GAC) were larger in size, and lower in density, causing higher porosity than the mono-medium sand. The particle sizes of influent water were too small in comparison with the higher porosity of the filter bed, having fewer opportunities to attach to the medium surface in a column. In addition, the small particles can not be aggregated to form flocculant particles without polymers. So the column with higher porosity has lower filtration efficiency.

Based on the above explanation, the filtration performance in fine sand filter (Filter 6, 0.35 mm in size) should be better than that in coarse sand filter (0.5 mm in size). That was the case. The particle counts in fine sand filter were lowest (~30 particles/mL). However, the turbidities of the effluent water from the fine sand filter were the highest

among all filters. The experiment was repeated twice and the same results were obtained. There is no explanation for this observation so far.

The headloss, effluent flowrate, and the filter run time are listed in Tables 4.2 and 4.3. Table 4.2 indicates that the change of headloss and effluent flowrate were less in the GAC-sand and anthticate-sand media filters in 24 hour run, whereas the change of headloss and flowrate in the control column with quartz sand was larger.

Figure 4.27 and Table 4.2 obviously showed that the breakthrough of anthracite-sand and GAC-sand filter beds were due to the saturation of particles on the filter media, whereas the breakthrough of quartz sand filter was from the development of headloss, which was predictable.

Table 4.3 showes that the fine sand filter developed headloss faster and the reduced effluent flowrate quicker than quartz sand filter did. However, Figure 4.28 showes that the fine sand filtration produced the best effluent water quality among all media filters without use of the polymer.

4.7.2 The Comparison of Various Media with Three Types of Polymers

The polymers and their dosages were listed in Table 4.4.

The results of three polymers used in the six columns were shown in Figures 4.29 to 4.31. The effect of Percol LT 24 polymer on coal-sand and fine-sand filters are shown in Figures 4.31 and 4.32. The results show that all the three polymers are able to improve

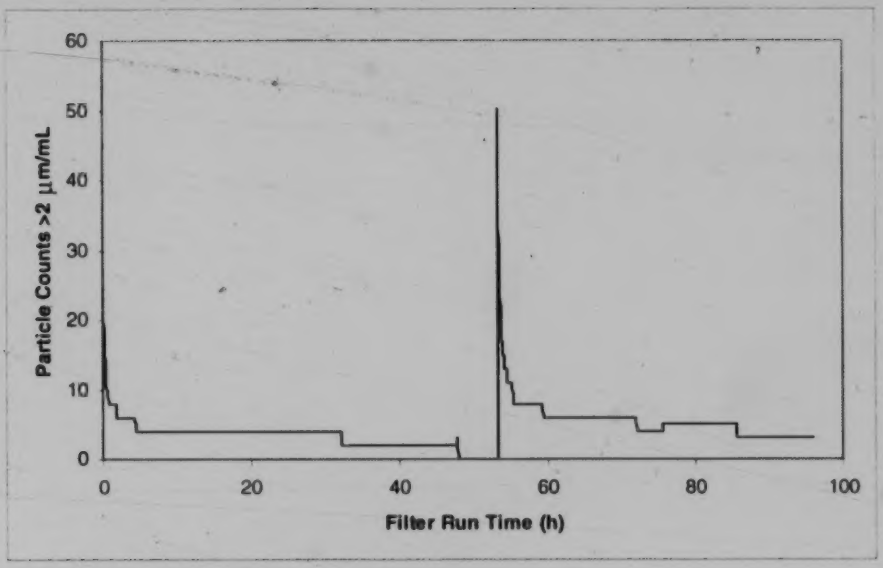
the effluent water quality, most effectively in anthracite-sand column in which not only was the effluent water quality improved, but also the filter run time was extended. The filter run time in anthracite-sand filter seemed to be restricted by the rapid increase of effluent particle counts in the absence of polymers, and by the rapid development of headloss of the filter in the presence of polymers. Figure 4.31 shows that similar effluent water qualities are obtained when using lower dose (0.001 mg/L) or higher dose LT 24 polymer (0.01 mg/L). But the filter run time increases to about 40 hours when using lower dose compared to 25 hour filter length when using 0.01 mg/L LT 24 polymer.

The filtration performance of the GAC-sand filter was not good, although the effluent water quality was improved by the polymer addition. Figure 4.30 indicate that the effluent particle counts of the GAC-sand column are from 150 particle/mL to 400 particle/mL, higher than 30 - 100 particle/mL of the anthracite-sand column. From the above results, it seems that the GAC-sand media filter is not suitable for the unsoftened water filtration in the Rossdale water treatment plant.

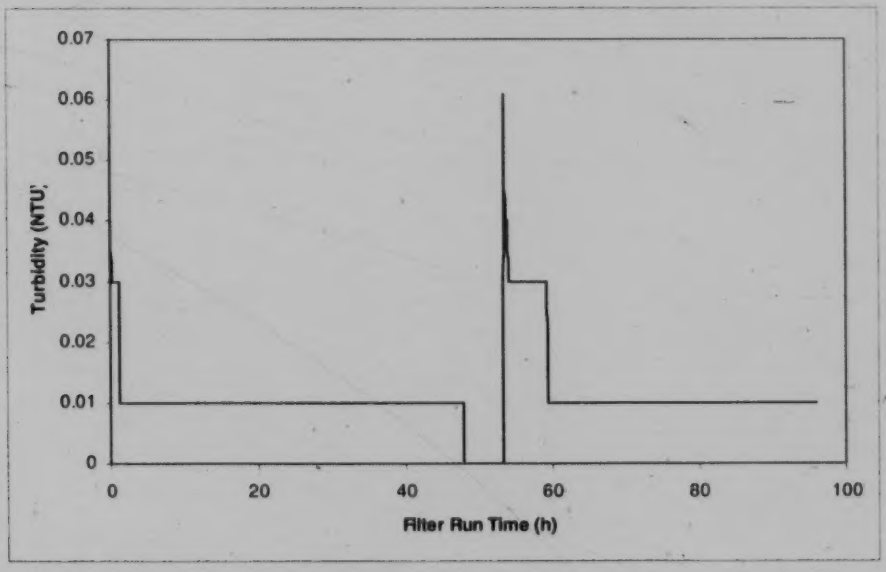
Fine sand column had very low effluent particle counts both in the absence of and in the presence of polymers and about 20 hours filter run length. Sometimes, the polymers can slightly improve the effluent turbidities. LT 24 polymer with the dosage 0.005 mg/L (see Figure 4.32) seemed to be the best for the fine sand column in which the effluent particle counts were about 30 particles/mL, turbidities about 0.12 NTU, and the filter run time was 22 hours. The effluent turbidities were higher than normal value because the influent turbidities were about 15 – 20 NTU.

The relationship of headloss and effluent flowrate with the filter run time were listed in Tables 4.5 to 4.10. The development of headloss and the reduction of effluent flowrate in coal-sand and GAC-sand media filters changed less than those in mono-media quartz sand filter with the use of three polymers. When the high dosage of polymer was used, the coal-sand filter expressed better filtration performance compared to the low dosage of polymers. Table 4.11 summarized the filtration performance of the anthracite-sand filter.

The fine sand (0.35 mm in size) filter had bigger headloss and quicker reduction of effluent flowrate than the quartz sand (0.5 mm in size) filter did no matter whether using polymers or not.

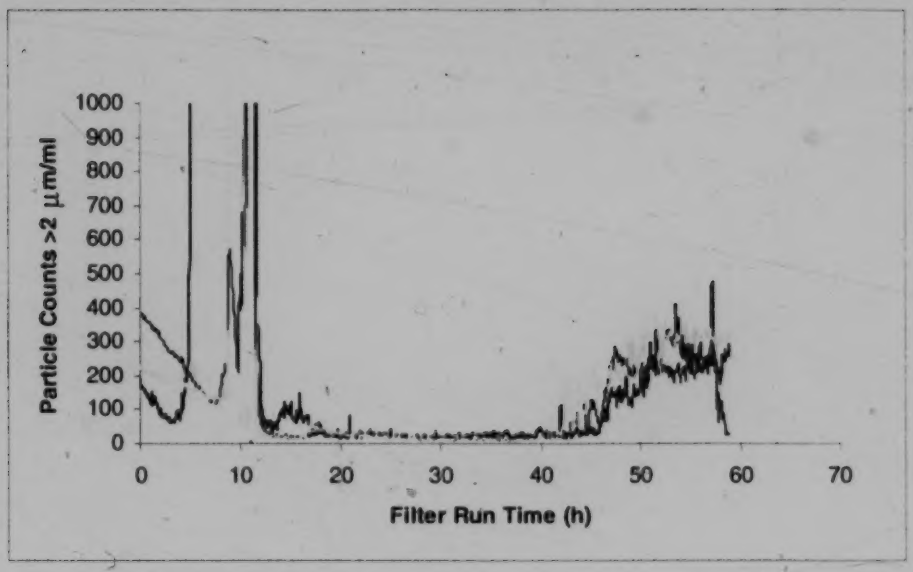


(a) Effluent Particle Counts *vs* Filter Run Time

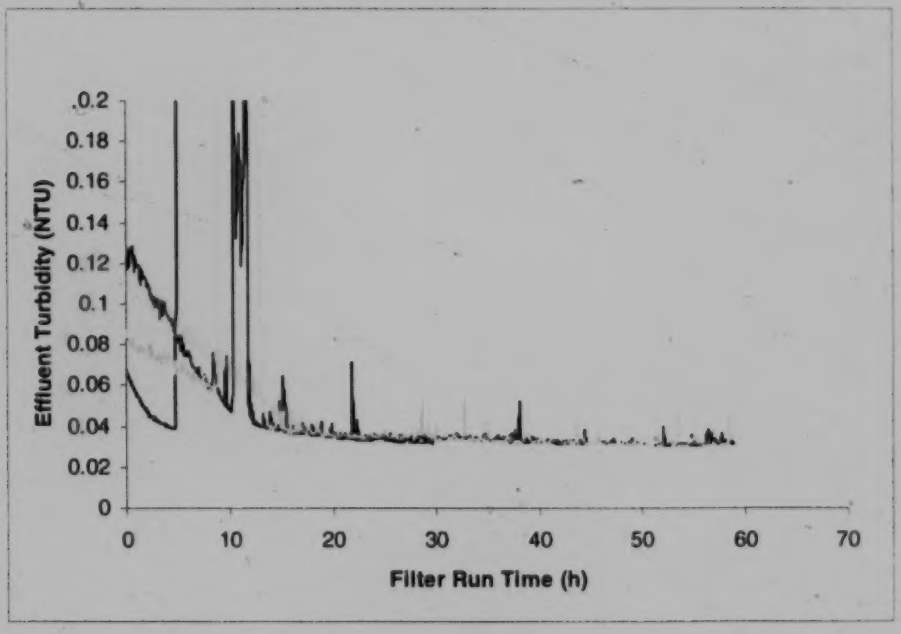


(b): Effluent Turbidity vs Filter Run Time

Figure 4.1: Full Scale Softened Water Filtration

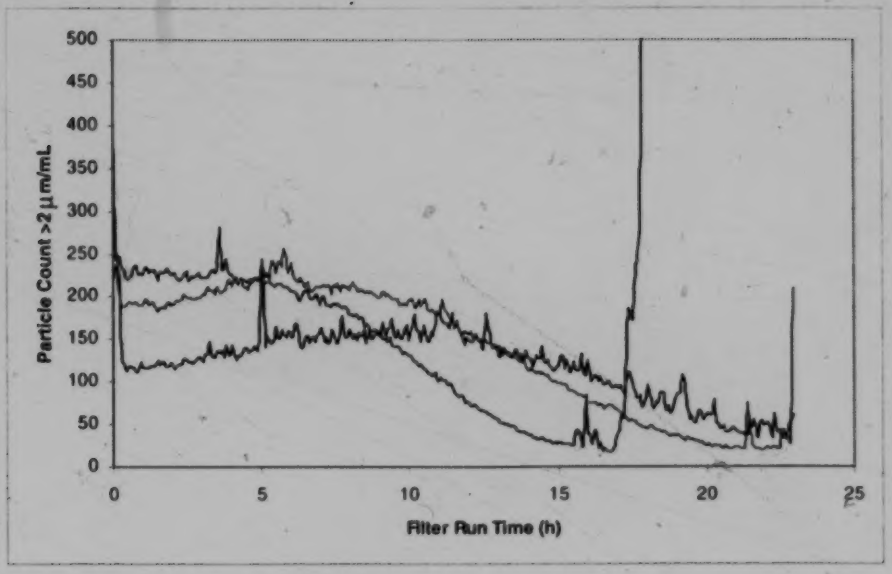


(a) Effluent Particle Counts *vs* Filter Run Time

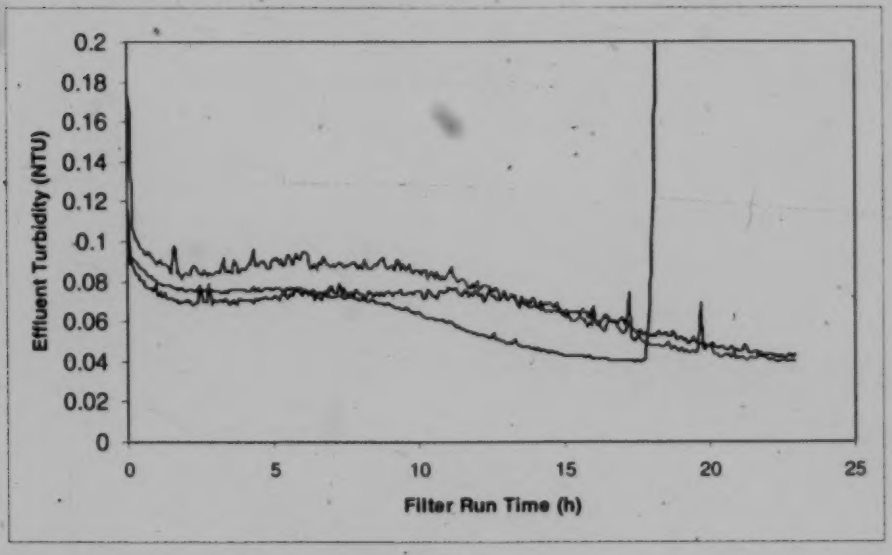


(b): Effluent Turbidity vs Filter Run Time

Figure 4.2: Pilot Plant Softened Water Filtration

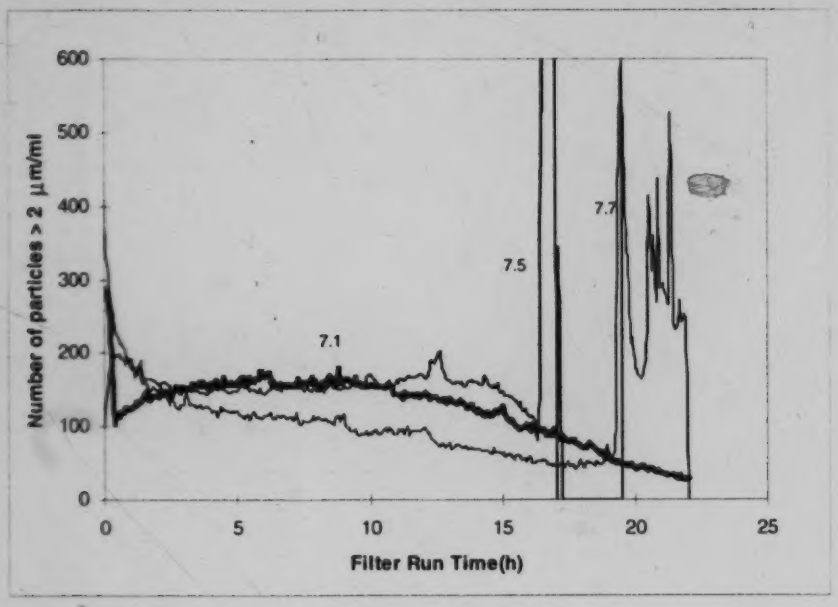


(a) Effluent Particle Counts *vs* Filter Run Time

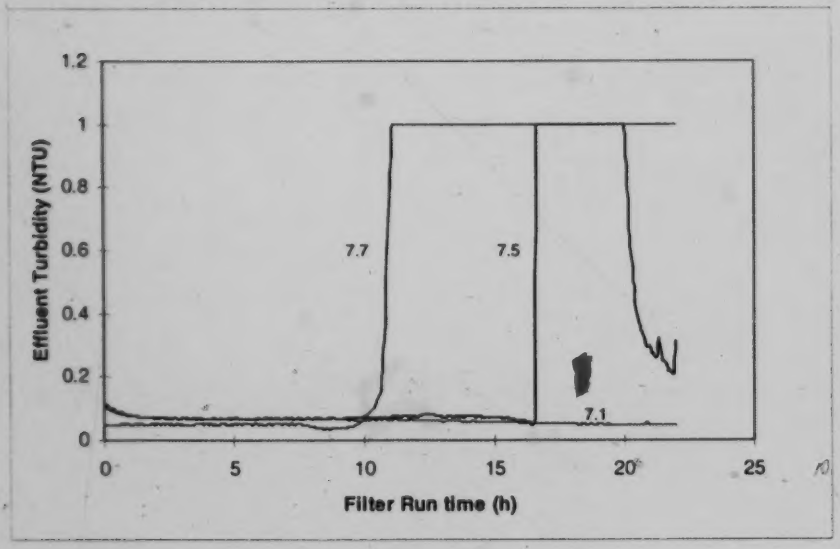


(b): Effluent Turbidity vs Filter Run Time

Figure 4.3: Pilot Plant Unsoftened Water Filtration

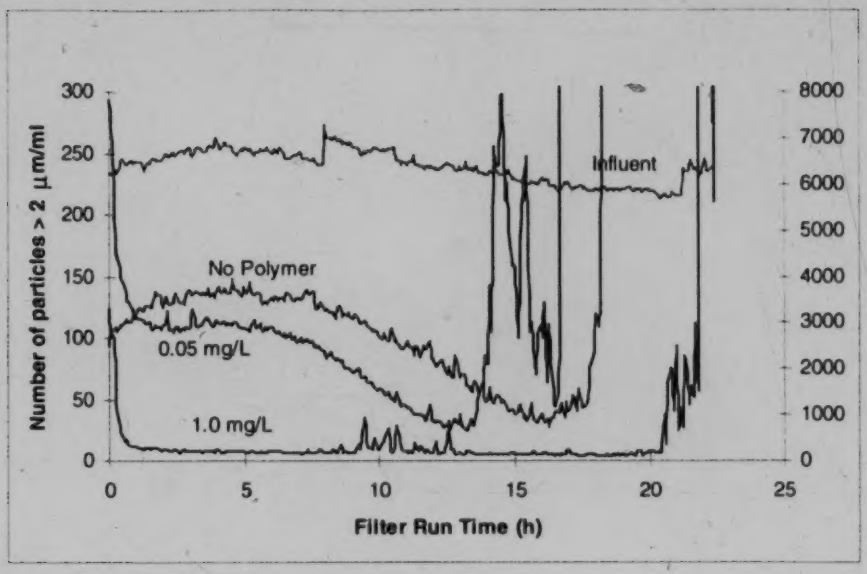


(a) Effluent Particle Counts *vs* Filter Run Time

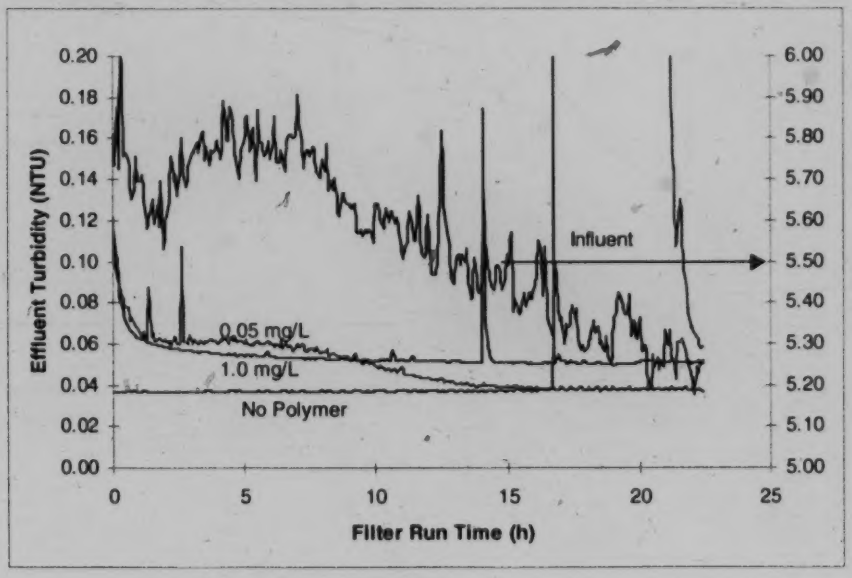


(b): Effluent Turbidity vs Filter Run Time

Figure 4.4: The Effect of pH on Effluent Water Quality

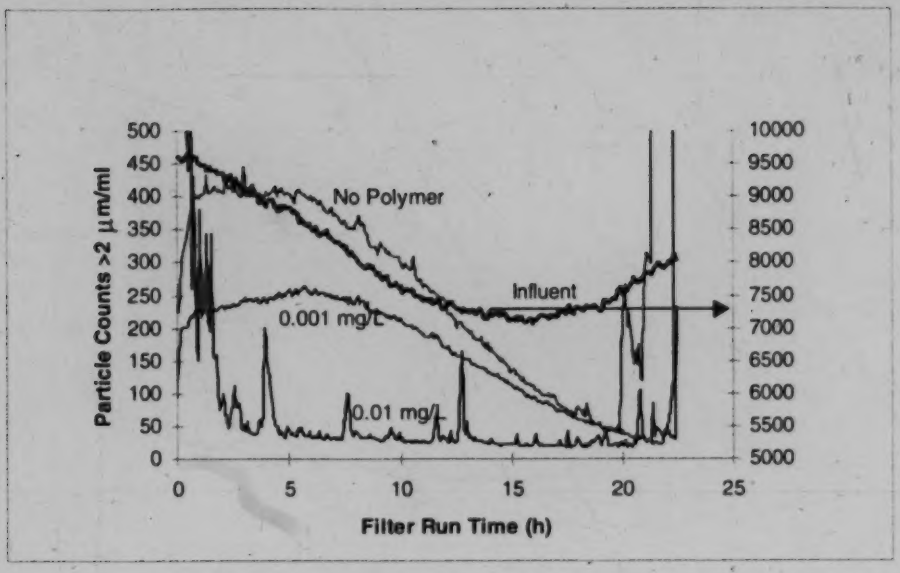


(a) Effluent Particle Counts *vs* Filter Run Time

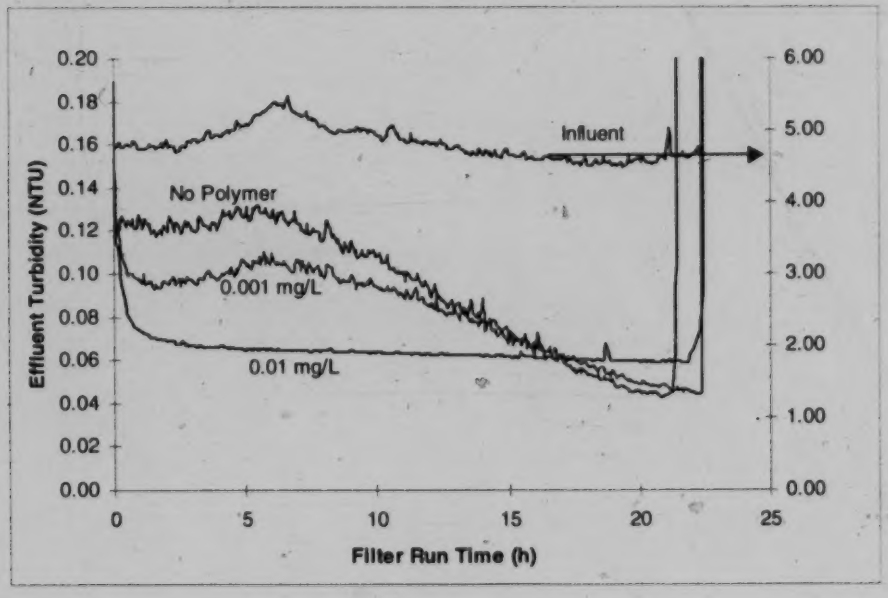


(b): Effluent Turbidity vs Filter Run Time

Figure 4.5: Nalcolyte 8100 Polymer Used as Filter Aid

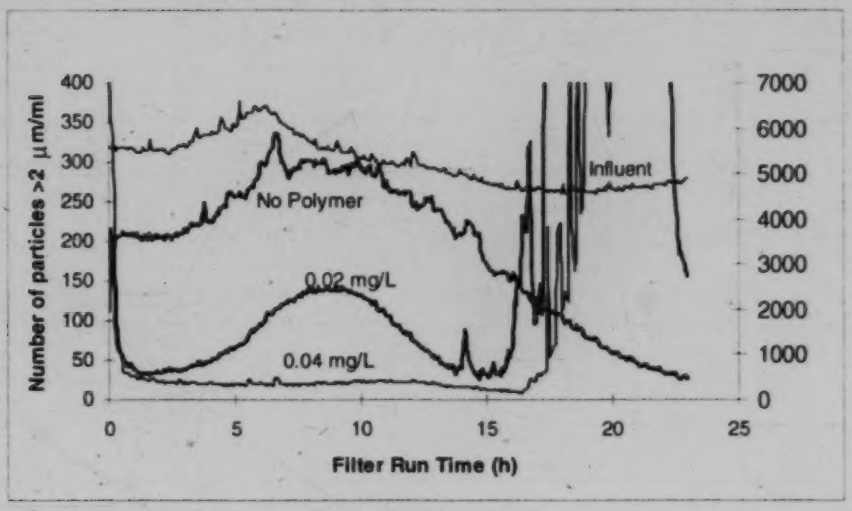


(a) Effluent Particle Counts *vs* Filter Run Time

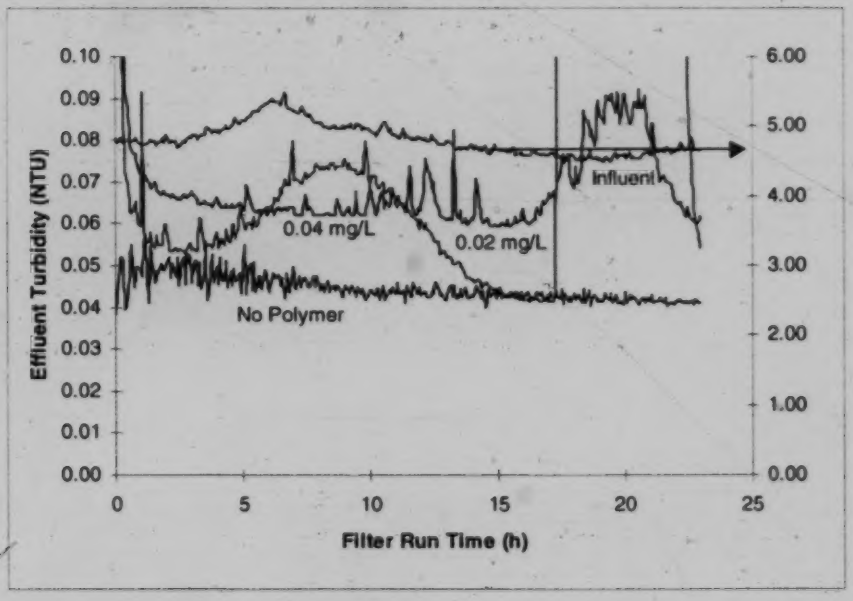


(b): Effluent Turbidity vs Filter Run Time

Figure 4.6: Percol LT 24 Polymer Used as Filter Aid

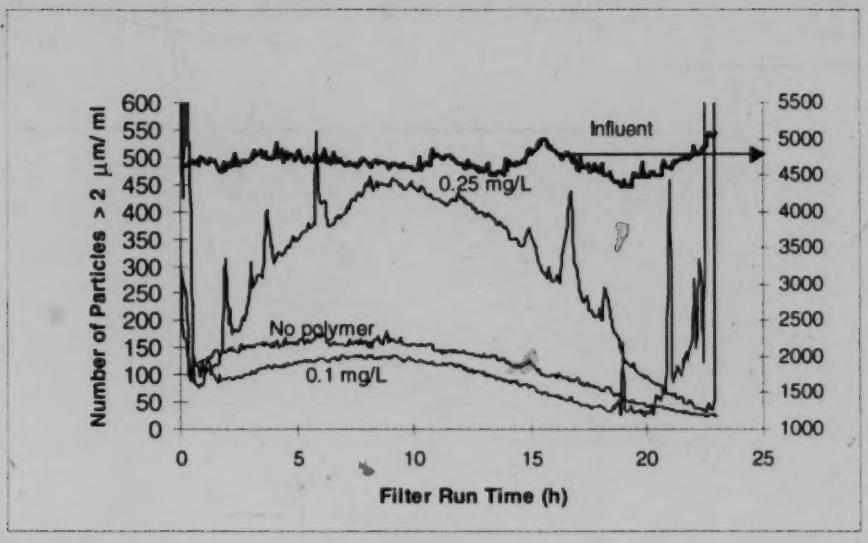


(a) Effluent Particle Counts *vs* Filter Run Time

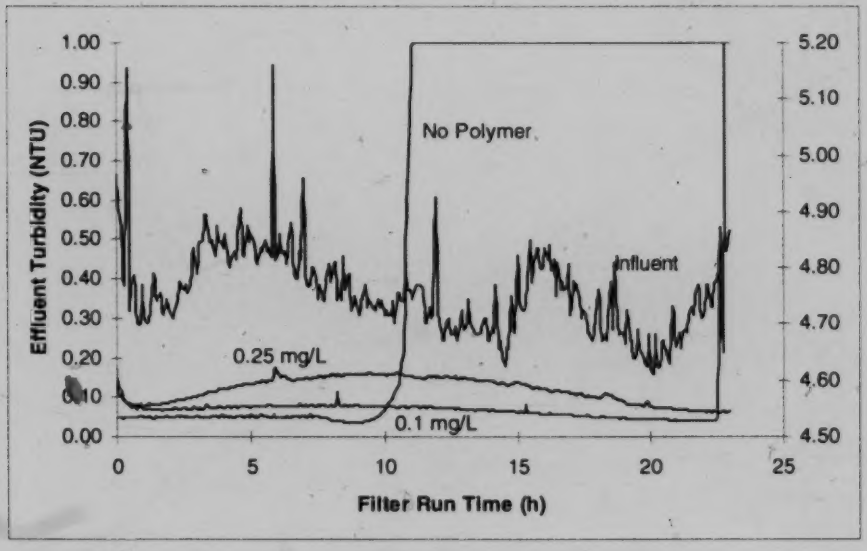


(b): Effluent Turbidity vs Filter Run Time

Figure 4.7: POL EZ 652 Polymer Used as Filter Aid

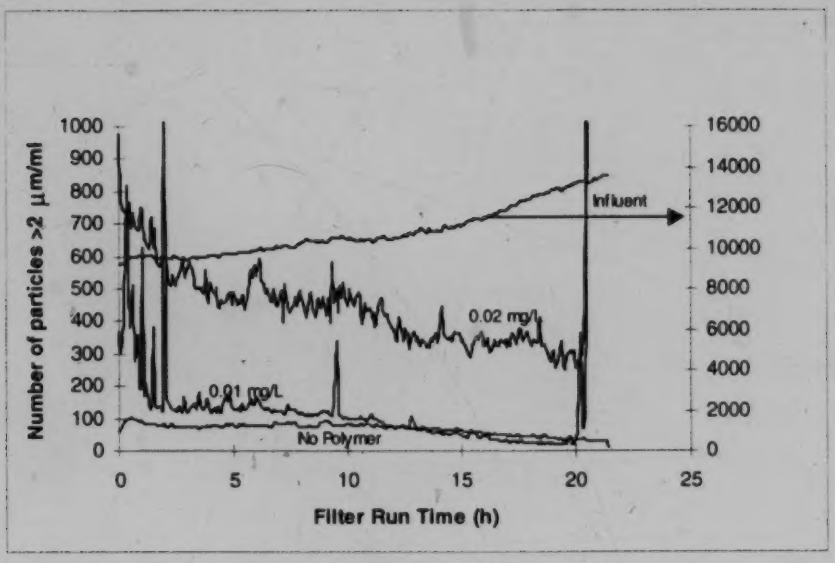


(a) Effluent Particle Counts *vs* Filter Run Time

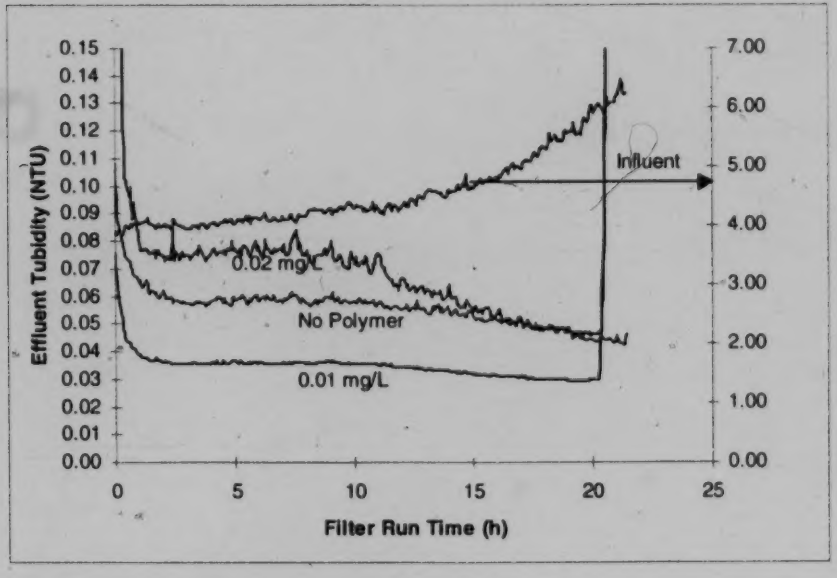


(b): Effluent Turbidity vs Filter Run Time

Figure 4.8: Percol LT 7996 Used as Filter Aid

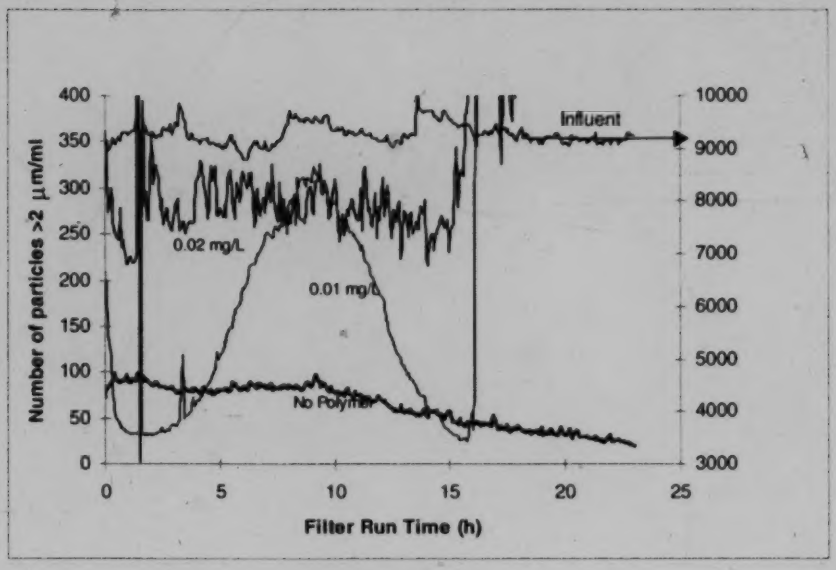


(a) Effluent Particle Counts *vs* Filter Run Time

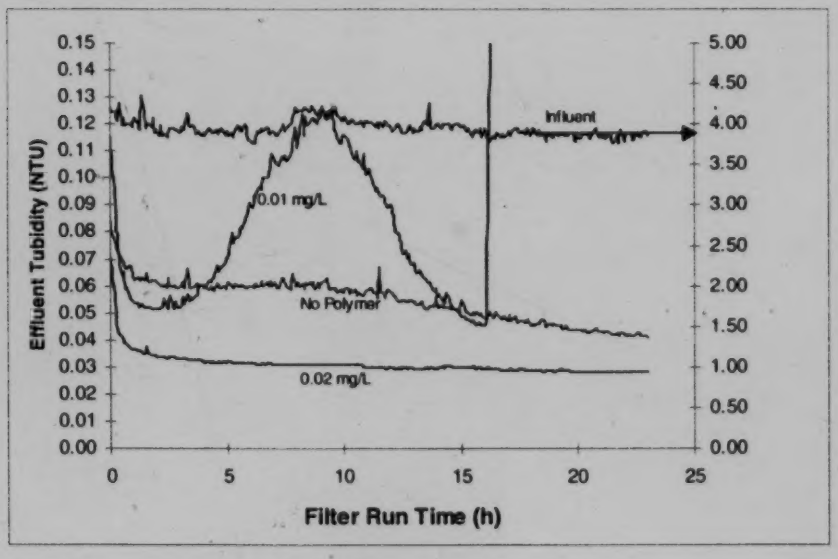


(b): Effluent Turbidity vs Filter Run Time

Figure 4.9: Percol LT 22 Polymer used as Filter Aid

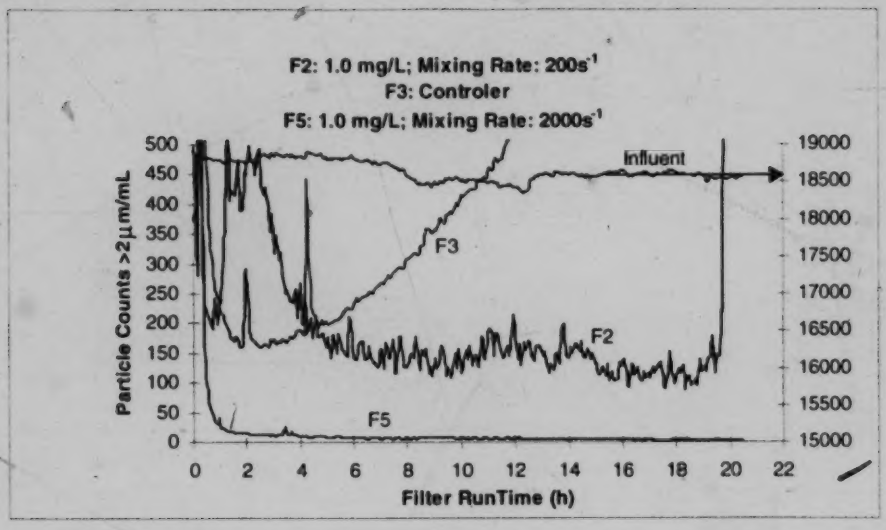


(a) Effluent Particle Counts *vs* Filter Run Time

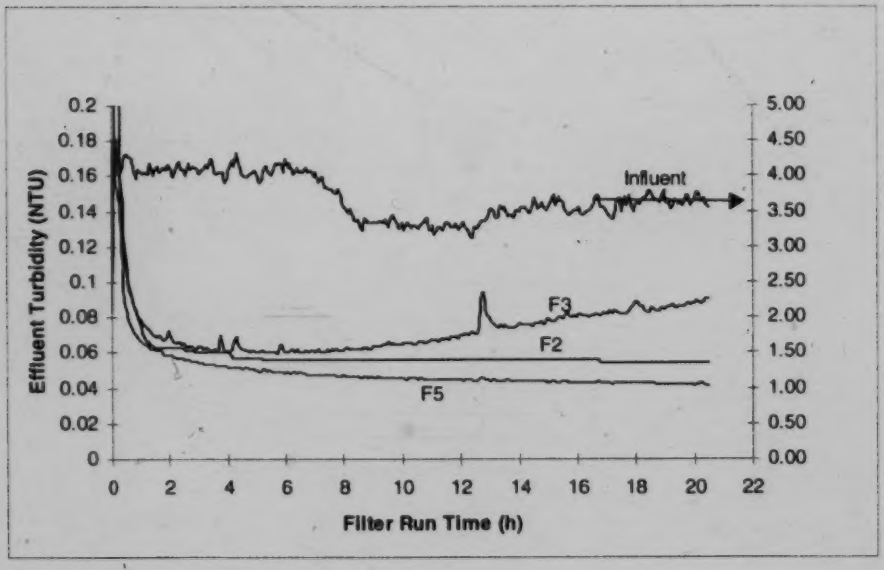


(b): Effluent Turbidity vs Filter Run Time

Figure 4.10: Percol LT 20 Polymer Used as Filter Aid

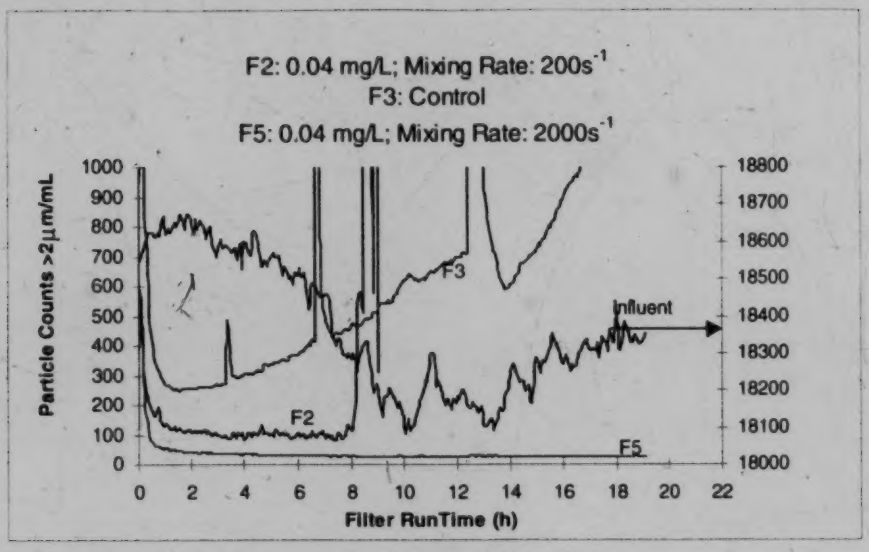


(a) Effluent Particle Counts *vs* Filter Run Time

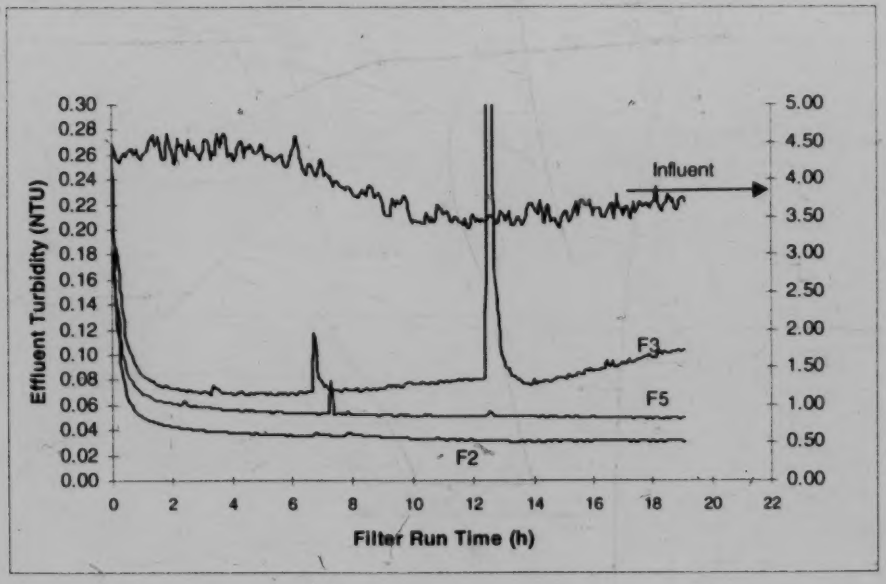


(b): Effluent Turbidity vs Filter Run Time

Figure 4.11: Mixing Intensity Test Using Nalcolyte 8100 Polymer

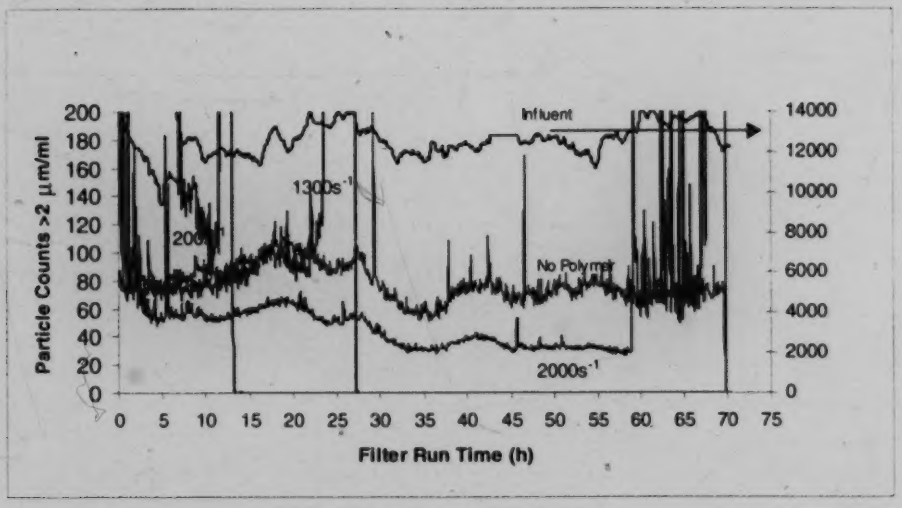


(a) Effluent Particle Counts *vs* Filter Run Time

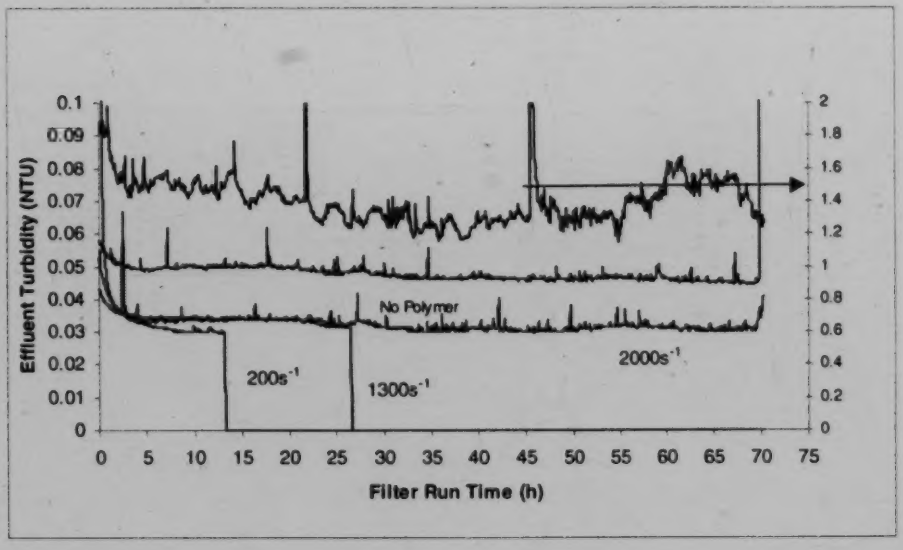


(b): Effluent Turbidity vs Filter Run Time

Figure 4.12: Mixing Intensity Test Using POL EZ 652 Polymer



(a) Effluent Particle Counts *vs* Filter Run Time



(b): Effluent Turbidity vs Filter Run Time

Figure 4.13: Mixing Intensity Test Using LT 24 Polymer (0.01 mg/L)

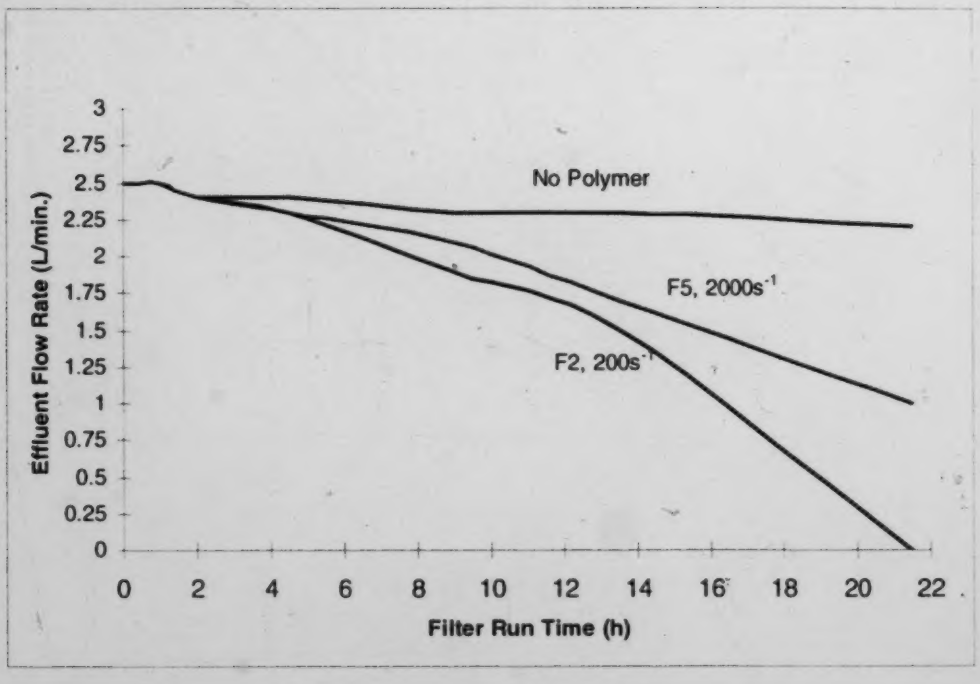


Figure 4.14: Effluent Flowrate vs FRT Using Nalcolyte 8100 Polymer

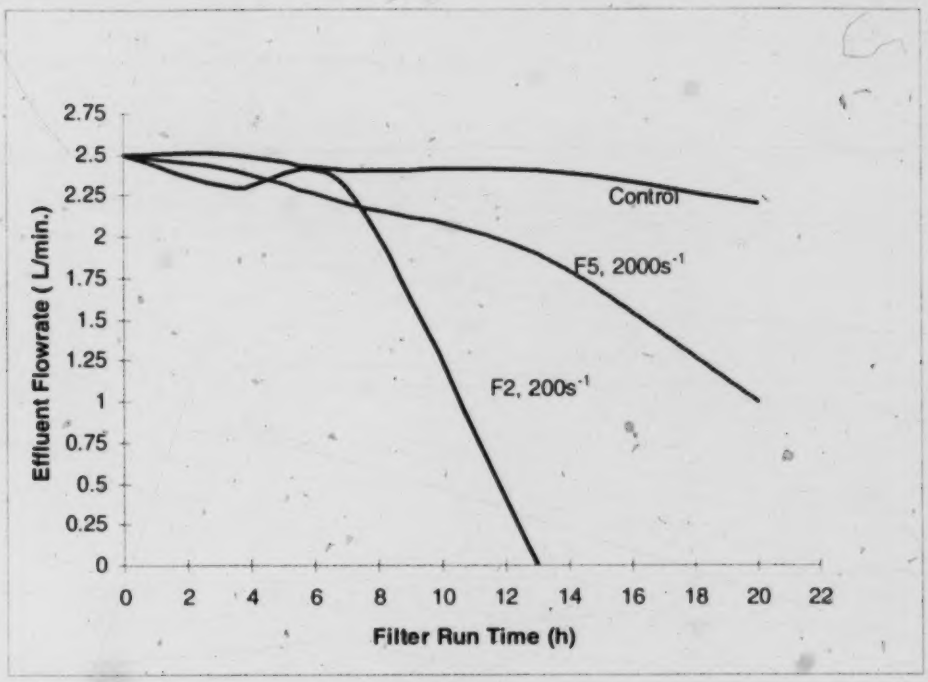


Figure 4.15: Effluent Flowrate vs FRT Using POL EZ 652 Polymer

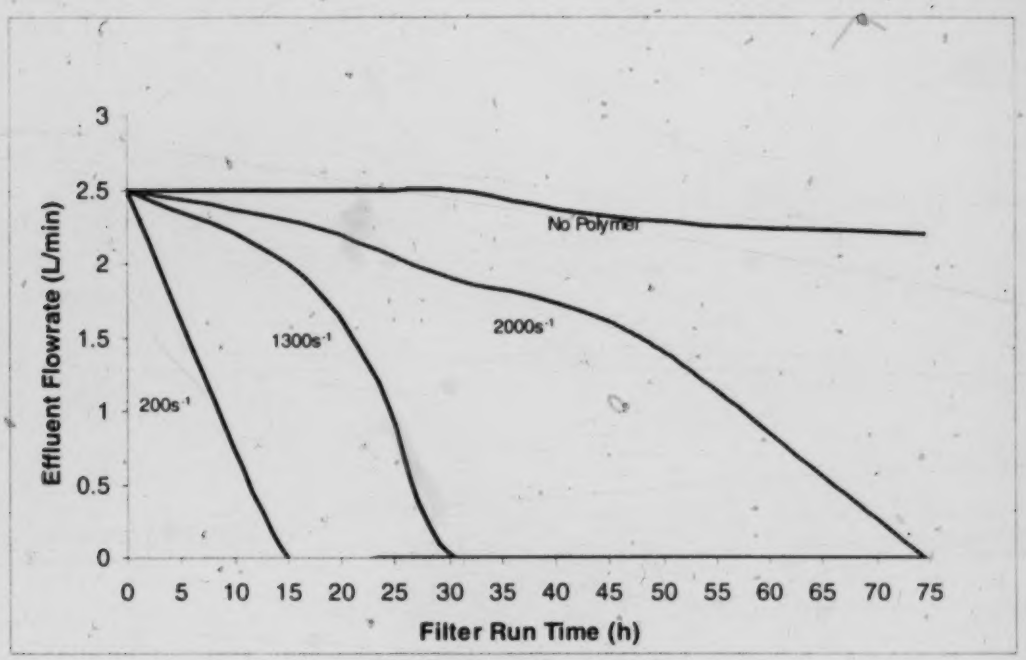


Figure 4.16: Effluent Flowrate vs FRT Using LT 24 Polymer (0.01 mg/L)

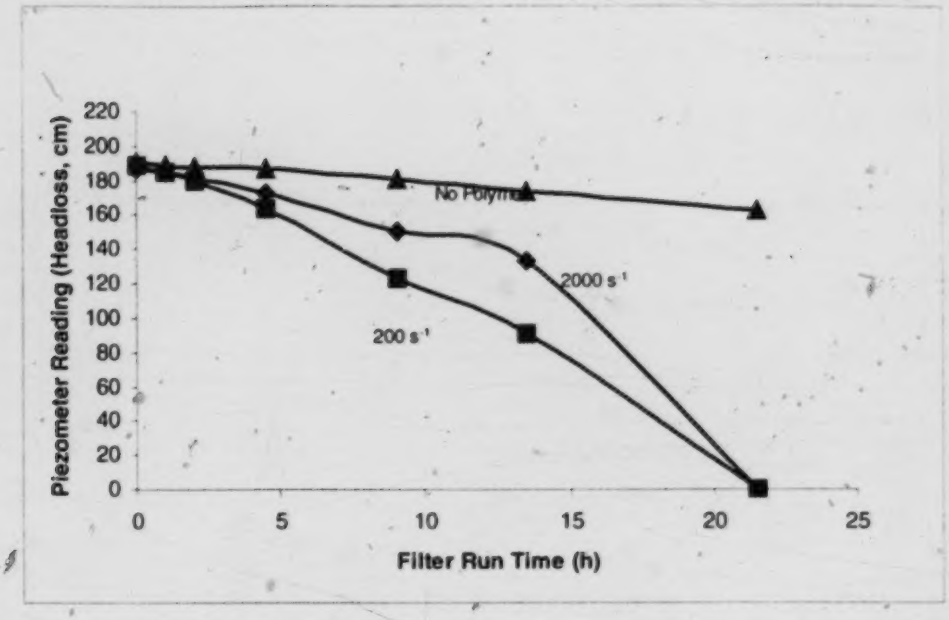


Figure 4.17: Headloss vs FRT Using Nalcolyte 8100 Polymer (1.0 mg/L)

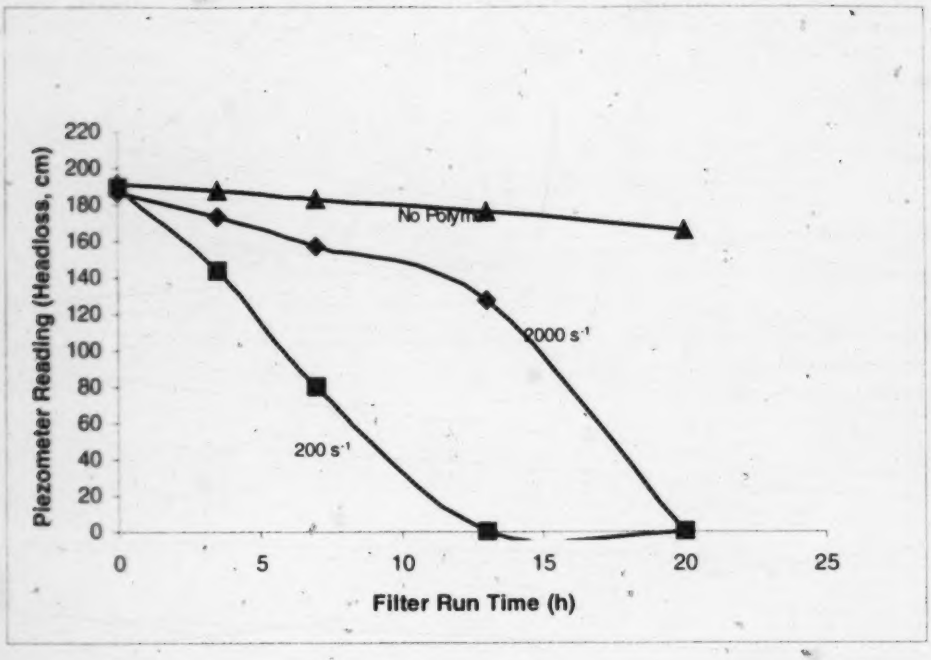


Figure 4.18: Headloss vs FRT Using POL EZ 652 Polymer (0.04 mg/L)

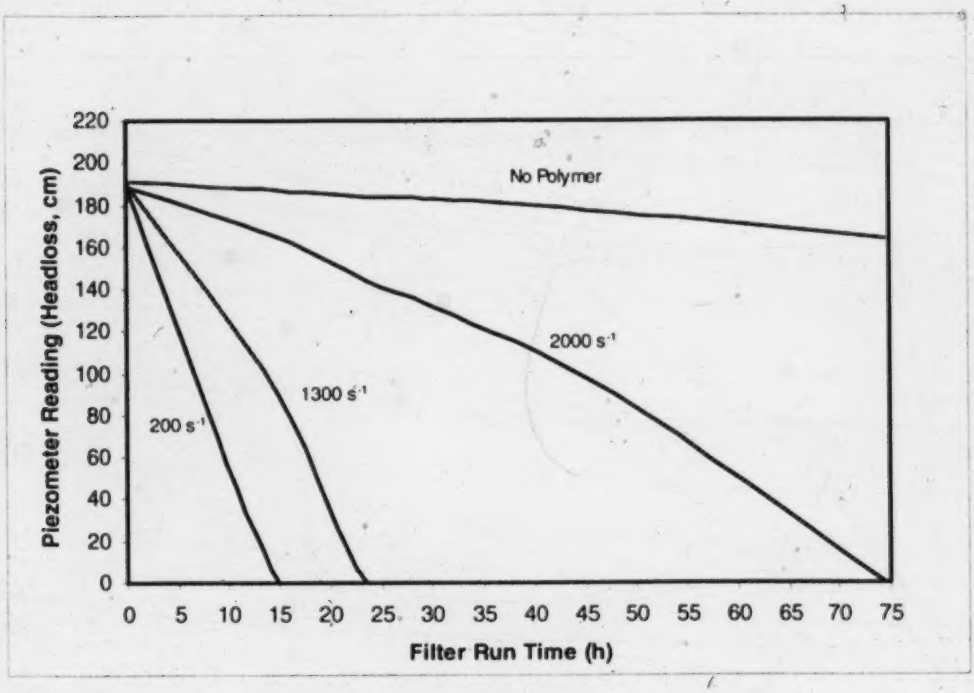
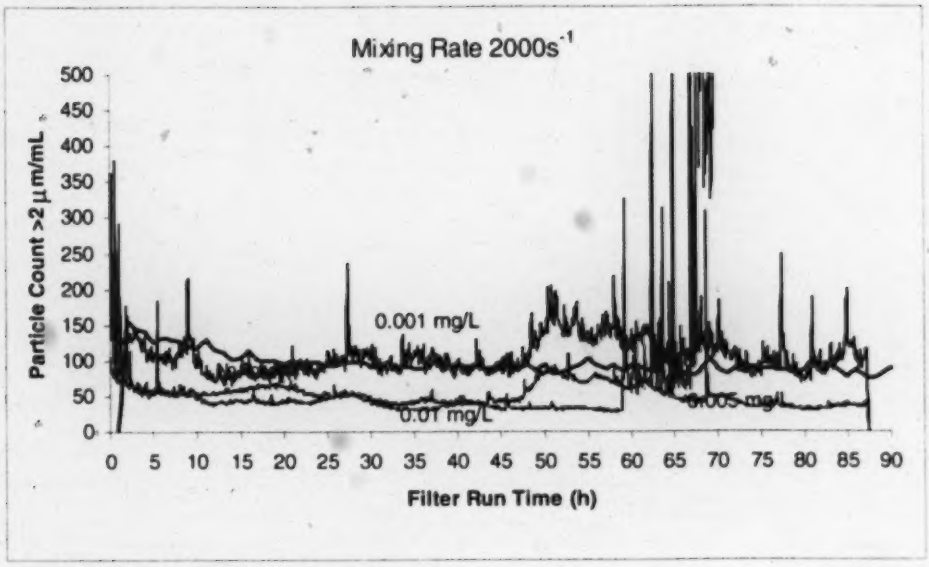
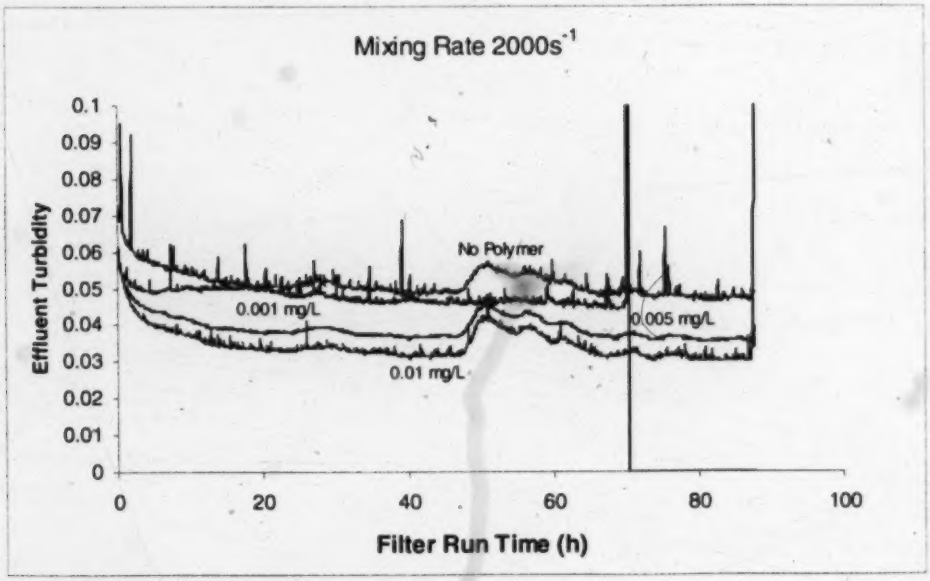


Figure 4.19: Headloss vs FRT Using LT 24 Polymer (0.01 mg/L)



(a) Effluent Particle Counts *vs* Filter Run Time



(b): Effluent Turbidity vs Filter Run Time

Figure 4.20: Dosage Test Using Percol LT 24 Polymer

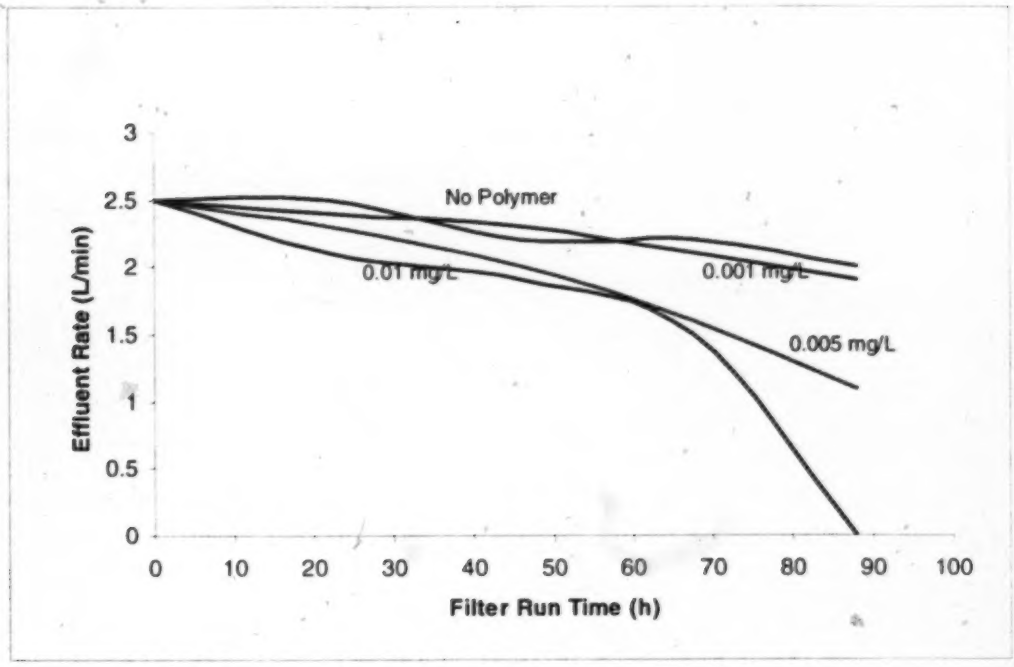


Figure 4.21: Effluent Flowrate vs FRT Using Percol LT 24 Polymer

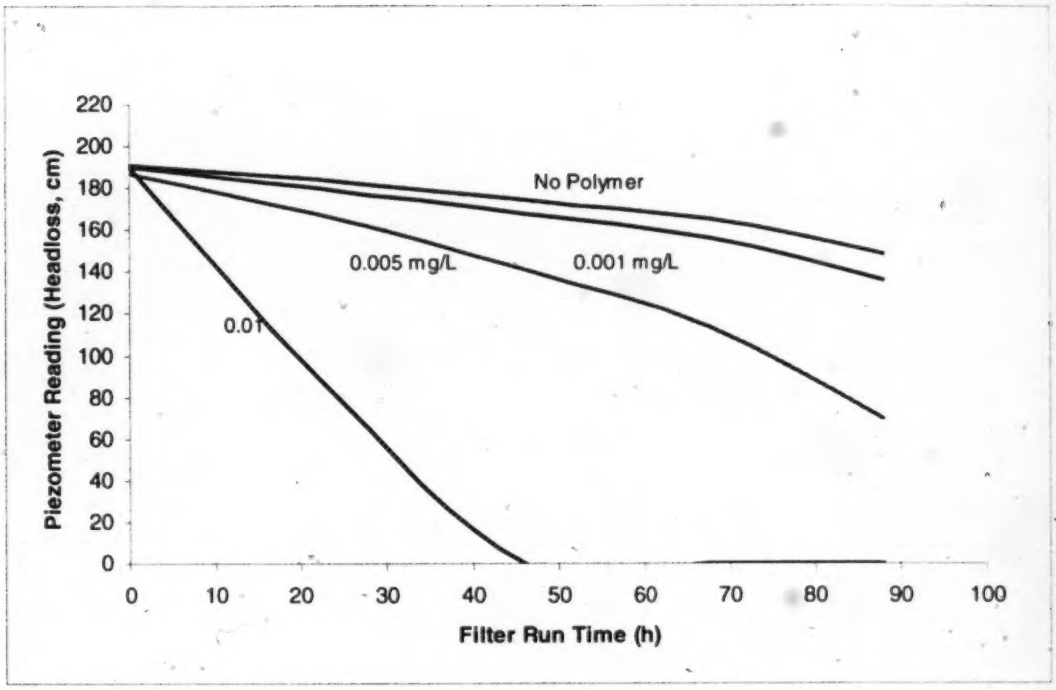
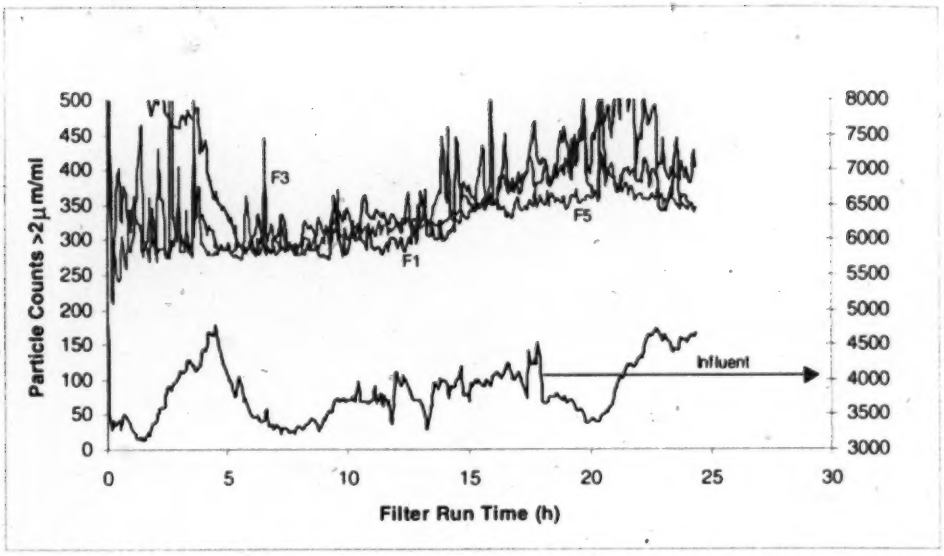
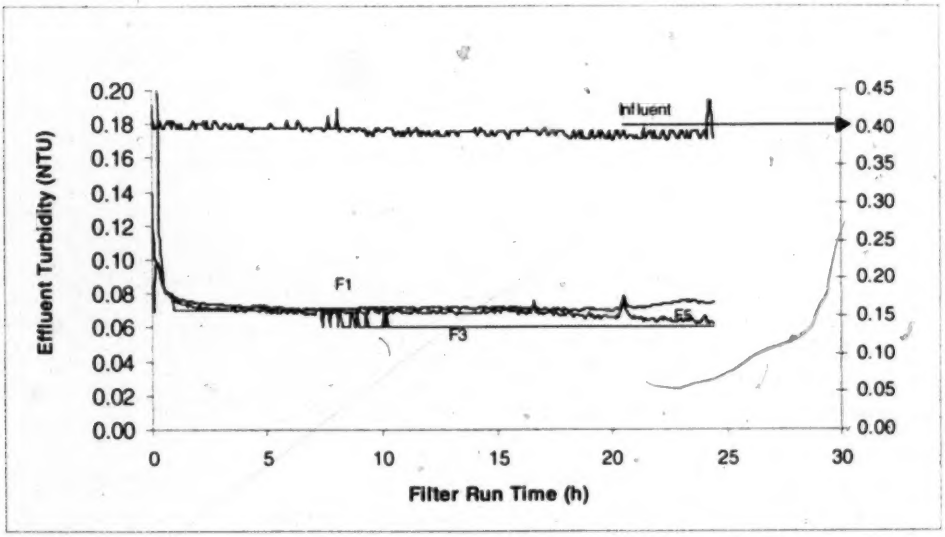


Figure 4.22: Headloss vs FRT Using Percol LT 24 Polymer



(a) Effluent Particle Counts *vs* Filter Run Time



(b): Effluent Turbidity vs Filter Run Time

Figure 4.23: Unsoftened Water Filtration without Polymer and PAC Addition

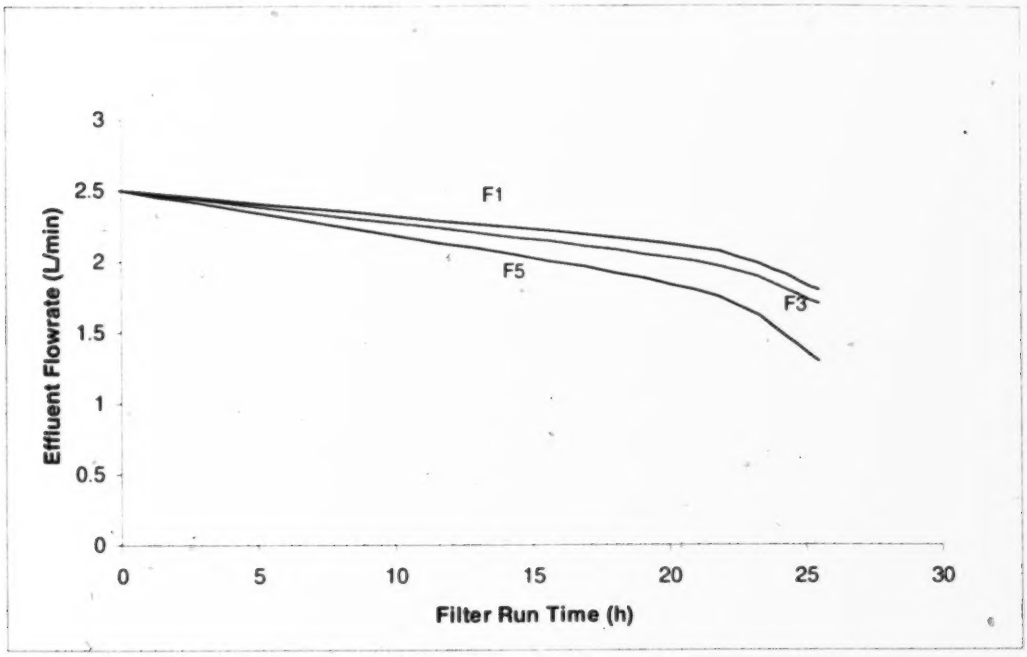


Figure 4.24: Effluent Flowrate vs FRT without Polymer and PAC Addition

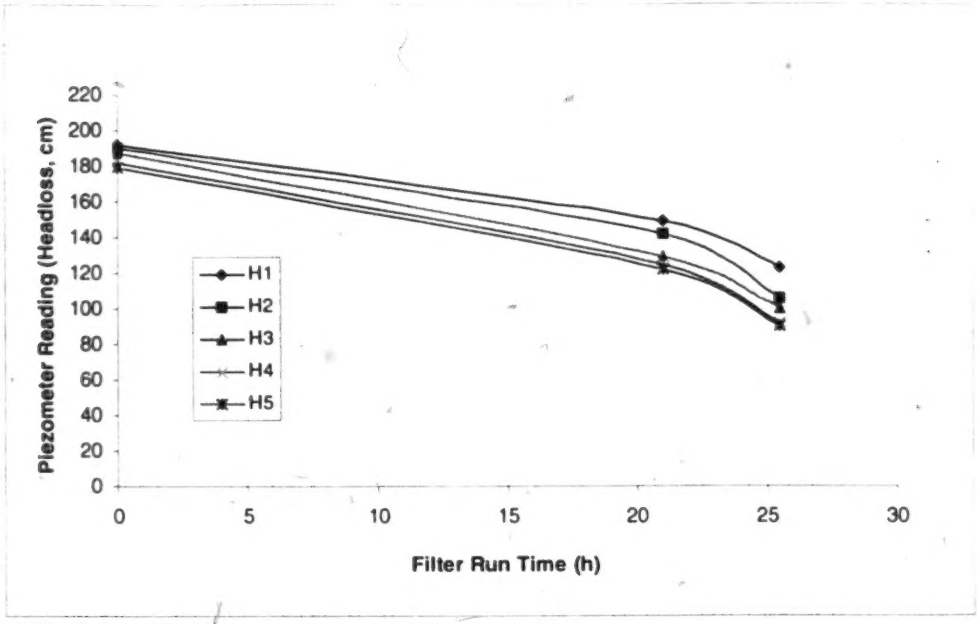
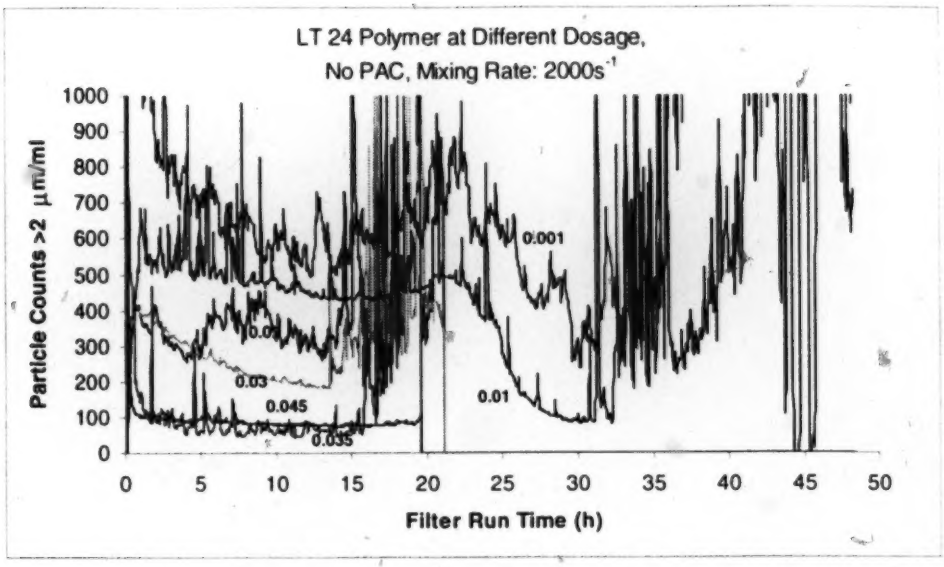
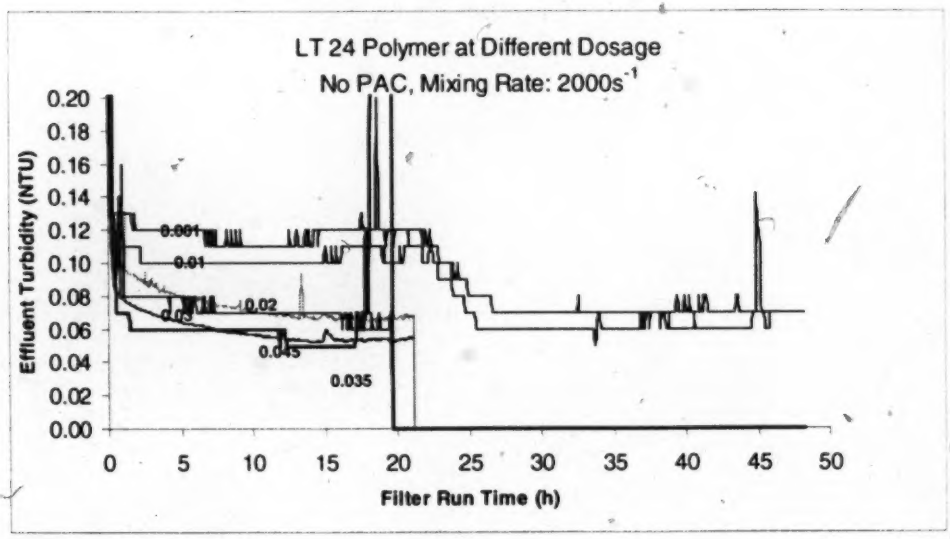


Figure 4.25: Headloss vs FRT without Polymer and PAC Addition

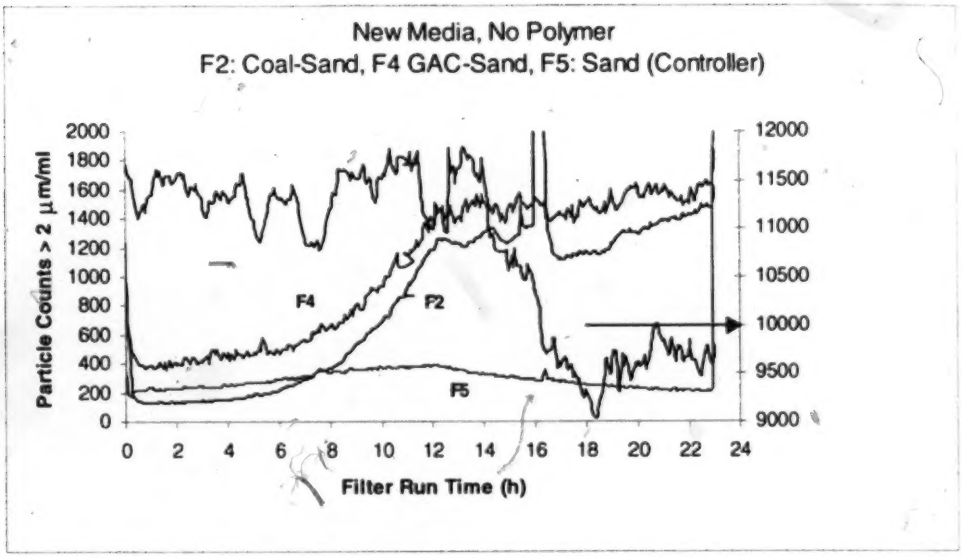


(a) Effluent Particle Counts *vs* Filter Run Time

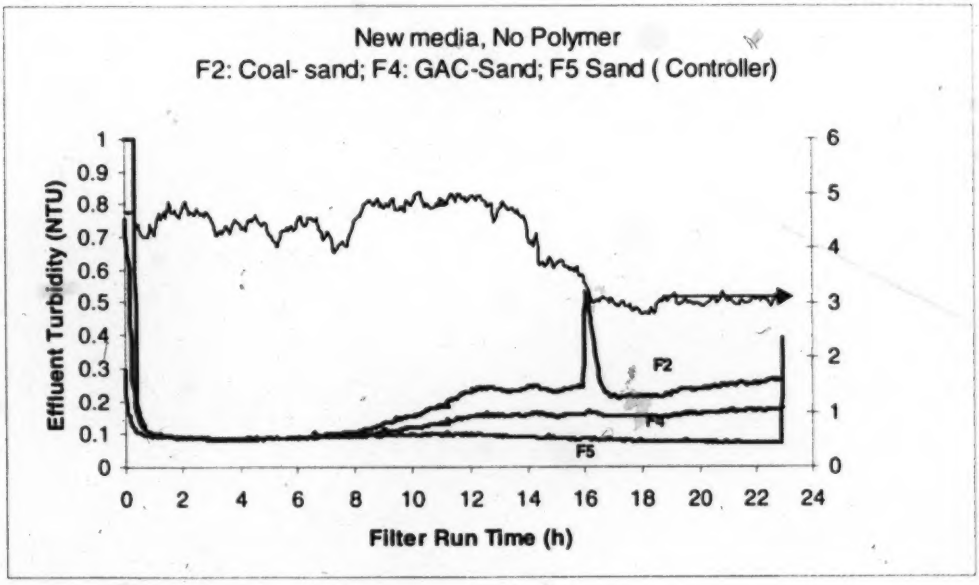


(b): Effluent Turbidity vs Filter Run Time

Figure 4.26: LT 24 Polymer Using as Filter Aid without PAC Addition

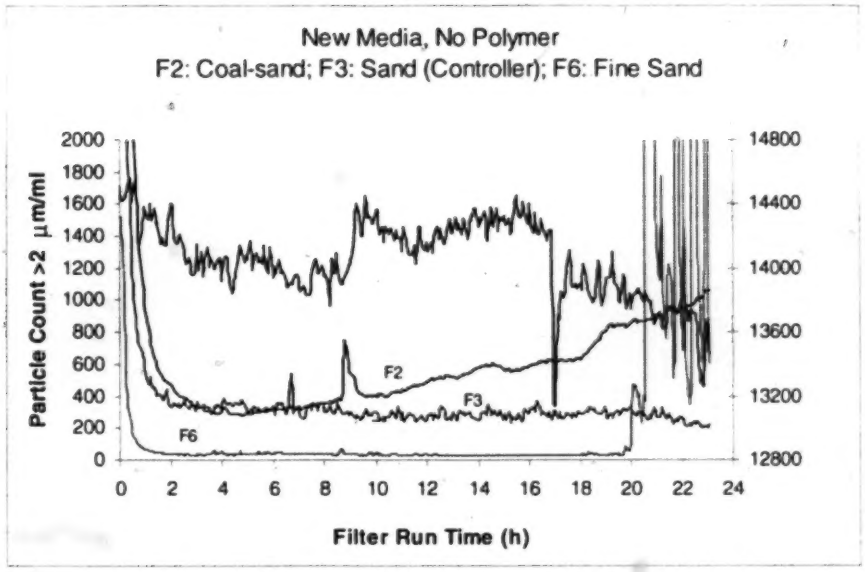


(a) Effluent Particle Counts *vs* Filter Run Time

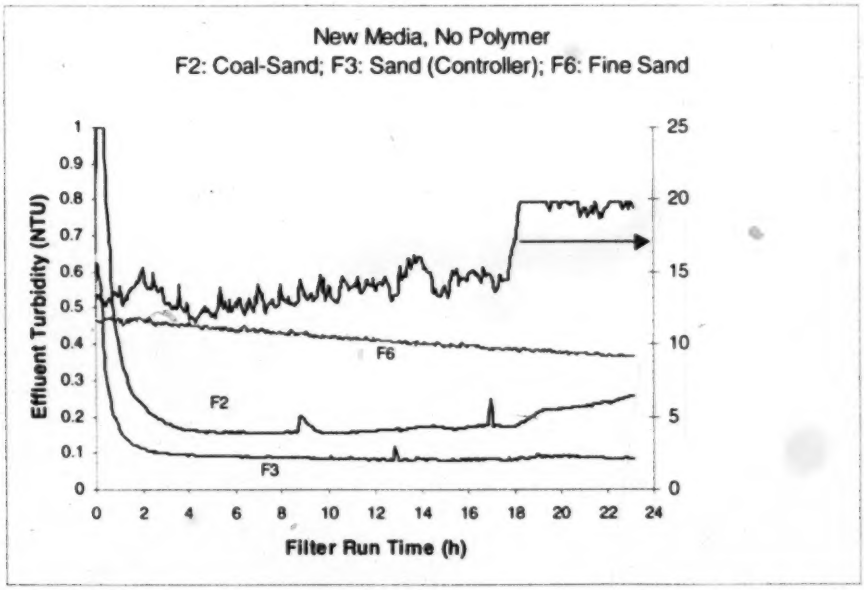


(b): Effluent Turbidity vs Filter Run Time

Figure 4.27: The Effect of Filter Media on Effluent Water Quality



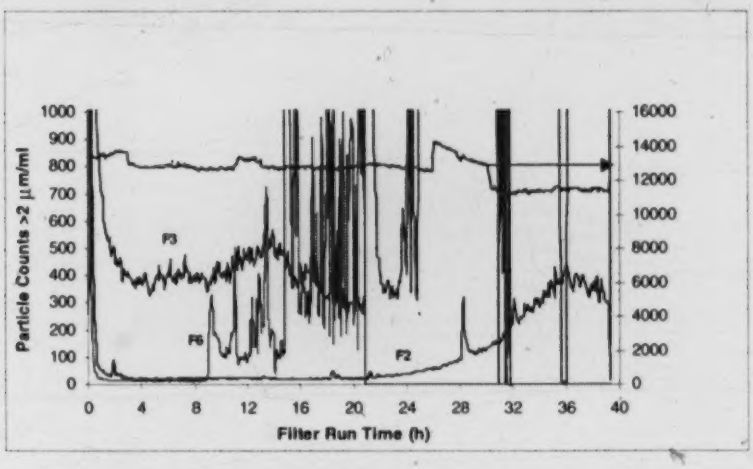
(a) Effluent Particle Counts *vs* Filter Run Time



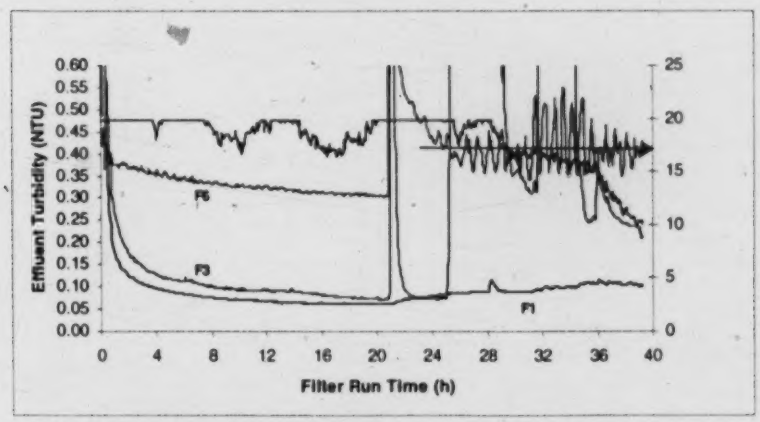
(b): Effluent Turbidity vs Filter Run Time

Figure 4.28: The Effect of Filter Media on Effluent Water Quality

	Filter2	Filter3	Filter6
Polymer	Nalcolyte 8100	No(Control)	Nalcolyte 8100
Dose (mg/L)	1.0	0.0	1.0
Filter Media	Coal-Sand	Sand	Fine Sand
Mixing (G)	2000 s^{-1}	200 s^{-1}	2000 s^{-1}



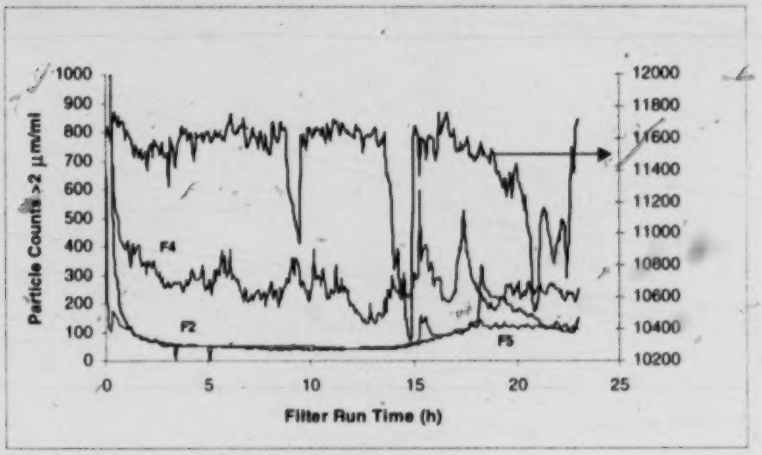
(a) Effluent Particle Counts *vs* Filter Run Time



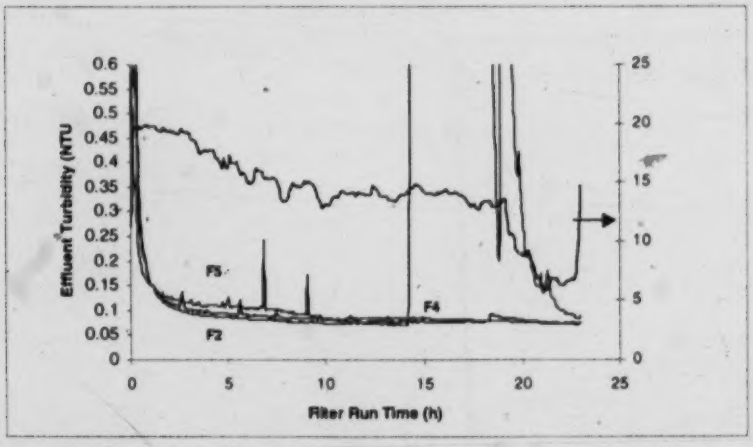
(b): Effluent Turbidity vs Filter Run Time

Figure 4.29: Different Media Filtration Using Nalcolyte 8100 Polymer

	Filter2	Filter4	Filter5
Polymer	Pol EZ 652	Pol EZ 652	No (Control)
Dose (mg/L)	0.02	0.02	0.0
Filter Media	Coal-Sand	GAC-Sand	Sand
Mixing (G)	2000 s^{-1}	2000 s^{-1}	200 s^{-1}

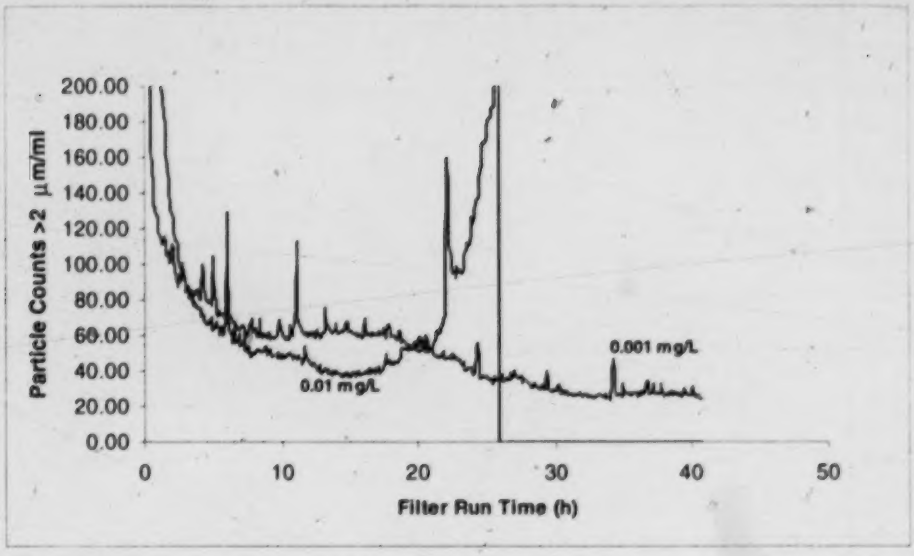


(a) Effluent Particle Counts *vs* Filter Run Time

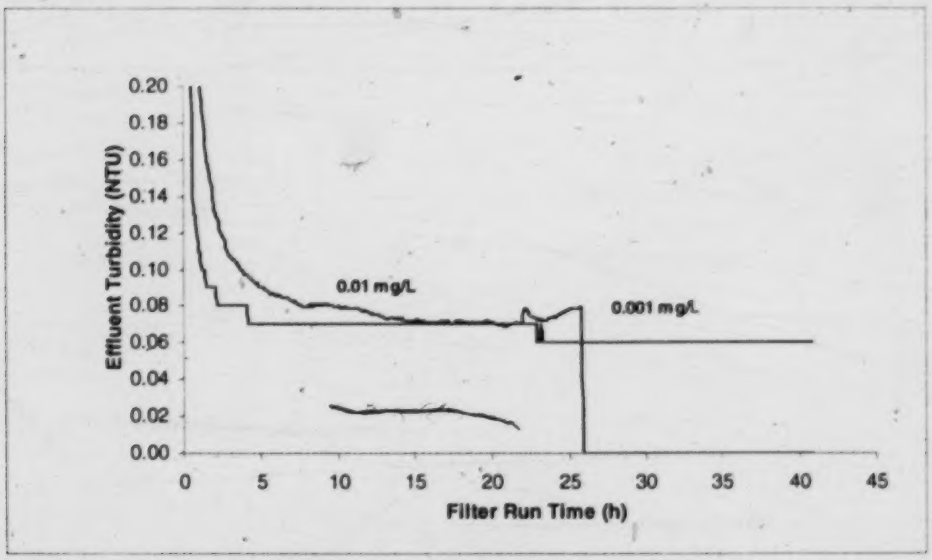


(b): Effluent Turbidity vs Filter Run Time

Figure 4.30: Different Media Using POL EZ 652 Polymer

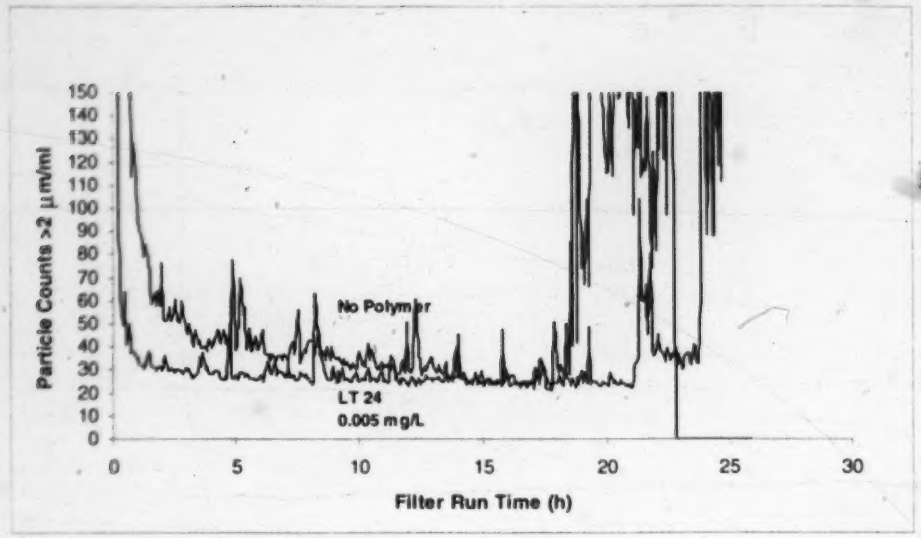


(a) Effluent Particle Counts *vs* Filter Run Time

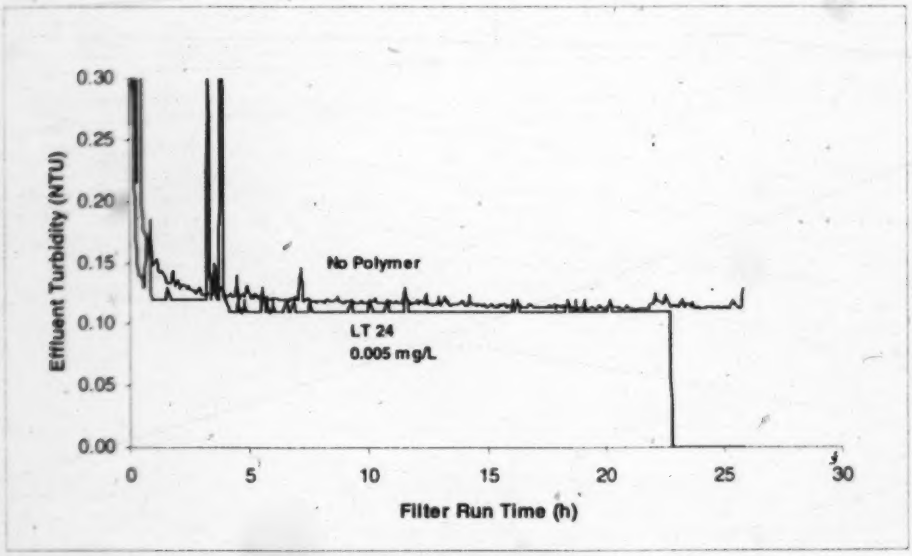


(b): Effluent Turbidity vs Filter Run Time

Figure 4.31: Coal-Sand Media Using Different Dose LT 24 Polymer



(a) Effluent Particle Counts *vs* Filter Run Time



(b): Effluent Turbidity vs Filter Run Time

Figure 4.32: Fine Sand Media With or Without Polymer

Table 4.1: Selected Polymers and Dosages

Polymer	Nalcolyte 8100	POL EZ 652	LT 7996	LT 20	LT22	LT 24
Type	Cationic	Non-ionic	Cationic	Non-ionic	Cationic	Cationic
MW	—	High	Low	High	High	Medium
Charge Density	—	No	High	No	Medium	Low
Dose (mg/L)	0.05, 1.0	0.02, 0.04	0.1, 0.25	0.01, 0.02	0.01, 0.02	0.001, 0.01
Particle Count (p/mL)	<50	<50	100	260	120	<50
Turbidity (NTU)	0.06	0.065	0.08	0.04	0.04	0.07
FRL (h)	<24	<24	<24	<24	<24	<24

Table 4.2: The Headloss and Effluent Flowrate

Headloss (cm)					
Anth-Sand		**No Polymer**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	187	182
24	190	183	181	171	166
GAC-Sand		**No Polymer**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	184	181
24	179	171	168	162	157
Quartz Sand		**No Polymer**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	190	184	181	174	171
24	98	64	0	0	0

Effluent Flowrate (L/min.)						
	Anth-Sand		GAC-Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
24	3	2.4	3	2.3	3	1.2

Table 4.3: The Headloss and Effluent Flowrate

Headloss (cm)

Anth-Sand **No Polymer**

Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	187	182
24	187	184	182	172	170

Fine Sand **No Polymer**

Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	185	179	167	162
24	0	0	0	0	0

Quartz Sand **No Polymer**

Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	189	185	181	177
24	161	155	151	143	141

Effluent Flowrate (L/min.)

	Anth-Sand		Fine Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
24	3	2.5	3	1.7	3	1.9

Table 4.4: Polymers used in the Filters

Polymer Name	Nalcolyte 8100	POL EZ 652	LT 24
Dosage (mg/L)	0.5 and 1.0	0.02 and 0.04	0.001, 0.005, 0.01

Table 4.5: The Headloss and Effluent Flowrate with Nalcolyte 8100 Polymer Addition

Headloss (cm)					
Anth-Sand		**Nalcolyte 8100, 1.0 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	187	182
22	177	166	164	156	153
41	151	134	131	118	115
Fine Sand		**Nalcolyte 8100, 1.0 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	191	190	184	181
22	0	0	0	0	0
41	0	0	0	0	0
Quartz Sand		**No Polymer**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	188	185	180	176
22	152	142	138	133	130
41	0	0	0	0	0

Effluent Flowrate (L/min.)						
	Anth-Sand		Fine Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
22	3	2.3	3	0	3	1.6
41	3	1.9	3	0	3	0

Table 4.6: The Headloss and Effluent Flow rate with Nalcolyte 8100 Polymer Addition

Headloss (cm)					
Anth-Sand	**Nalcolyte 8100, 0.5 mg/L**				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	187	182
24	172	166	165	160	156
47	100	92	90	78	76
GAC-Sand	**Nalcolyte 8100, 1.0 mg/L**				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	191	190	184	181
24	127	125	122	116	114
47	0	0	0	0	0
Quartz Sand	**No Polymer**				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	170	165	163	158	152
24	142	134	130	123	118
47	0	0	0	0	0

Effluent Flowrate (L/min.)						
	Anth -Sand		GAC-Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
24	3	2.4	3	2	3	2.2
47	3	1.7	3	0	3	0

Table 4.7: The Headloss and Effluent Flowrate with POL EZ 652 Polymer Addition

Headloss (cm)

Anth-Sand	POL EZ 652, 0.04 mg/L				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	187	182
24	182	167	165	152	148
43	105	103	98	84	82

GAC-Sand	POL EZ 652, 0.04 mg/L				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	191	190	184	181
24	151	142	140	133	130
43	0	0	0	0	0

Quartz Sand	No Polymer				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	187	184	180	173	170
24	114	132	124	116	112
43	0	0	0	0	0

Effluent Flowrate (L/min.)

	Anth-Sand		GAC-Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
24	3	2.3	3	2.1	3	2
43	3	1.7	3	0	3	0

Table 4.8: The Headloss and Effluent Flowrate with POL EZ 652 Polymer Addition

Headloss (cm)					
Anth-Sand		**POL EZ 652, 0.02 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	187	182
24	185	168	165	155	147
GAC-Sand		**POL EZ 652, 0.02 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	191	190	184	181
24	146	138	136	127	125
Fine Sand		**POL EZ 652, 0.02 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	185	180	167	161
24	0	0	0	0	0
Quartz Sand		**No Polymer**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	187	184	180	173	170
24	0	0	0	0	0

Effluent Flowrate (L/min.)						
	Anth -Sand		GAC-Sand		Fine & Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
24	3	2.3	3	2.2	3	0

Table 4.9: The Headloss and Effluent Flowrate with Percol LT 24 Polymer Addition

Headloss (cm)					
Anth-Sand	**Percol LT 24, 0.01 mg/L**				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	184	180
23	189	182	180	166	163
50	187	180	177	163	159
GAC-Sand	**Percol LT 24, 0.01 mg/L**				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	191	190	184	181
23	177	171	168	159	156
50	0	0	0	0	0
Quatz Sand	**No Polymer**				
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	184	181
23	99	94	91	87	82
50	0	0	0	0	0

Effluent Flowrate (L/min.)						
	Anth-Sand		GAC-Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
23	3	2.5	3	2.2	3	1.4
50	3	2.4	3	0	3	0

Table 4.10: The Headloss and Effluent Flowrate with Percol LT 24 Polymer Addition

Headloss (cm)					
Coal-Sand		**Percol LT 24, 0.001 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	184	180
25	190	184	182	167	163
Fine Sand		**Percol LT 24, 0.005 mg/L**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	192	185	181	169	163
25	0	0	0	0	0
Quartz Sand		**No Polymer**			
Time (hr)	Piezometer1	Piezometer2	Piezometer3	Piezometer4	Piezometer5
0	191	191	190	184	181
25	120	112	110	99	93

Effluent Flowrate (L/min.)						
	Anth-Sand		GAC-Sand		Quartz Sand	
Time (hr)	Influent	Effluent	Influent	Effluent	Influent	Effluent
0	3	2.5	3	2.5	3	2.5
25	3	2.4	3	0.9	3	0

Table 4.11: The Filtration Performance of Anthracite-Sand Media

	Nalcolyte 8100 (mg/L)		POL EZ 652 (mg/L)		LT 24 (mg/L)	
	0.5	1.0	0.02	0.04	0.001	0.01
Effluent particle count (particle/ml)	20-60	30-35	40–50	30-80	40-70	40-45*
Effluent Turbidity (NTU)	0.07-0.14	0.06-0.1	0.09	0.06-0.08	0.06	0.07
Filter run time (hr)	40	21	15*	43	40	21*
Remark			* breakthrough is due to the effluent particle counts		* breakthrough is due to the headloss	

5 Conclusions

In this study, polymer aid filtration under various operating conditions was investigated. From the experimental results and analyses, the following can be concluded: It should be noted that these results are mainly applicable for the Rossdale water treatment plant.

1. Polymers as filter aids, especially the cationic polymers for unsoftened water filtration, present several advantages for effective removal of particles in filtration process. Compared to no polymer aid filtration, the polymer aid filtration produces water with lower effluent particle counts and turbidities, has more consistent effluent water quality, longer filter run time, and shorter ripening time. However, it also causes larger headloss and larger decline of effluent flowrate. It seems that the best polymer dosage is dependent on the influent particle numbers, so the dosage changes by seasons and water qualities. From the experimental data and the integrated evaluation of some parameters such as effluent particle count, turbidity, filter run length as well as the headloss and effluent flowrate across a filter, Percol LT 24 polymer (cationic, medium molecular weight) presented the best filtration performance as a filter aid among the six types of polymers tested. In this study on polymer aid filtration, interparticle bridging model is more appropriate in explaining some experimental results than the charge neutralization model.

2. Mixing intensity in polymer mixing tanks has a significant effect on the performance of polymers. The mixing intensity of $G = 2000s^{-1}$ shows the best filtration performance in the study in terms of effluent water and filter breakthrough no matter what the polymer

dosage was. Especially, it has a marked effect on the filter run length. The higher the mixing rate, the longer the filter run time.

3. Polymers as filter aids do not result in satisfactory effluent water qualities in all seasons due to the raw water quality variations by season. Powder activated carbon (PAC) added prior to filtration can not only reduce particle counts and turbidities, but also remove odor and color of the water. When PAC is used, the polymer aid filtration shows the best filtration performance in all the experimental runs. At the same time, the amount of polymers used in filtration can be largely reduced.

4. Filter media greatly affects the performance of polymer aided filtration. In this investigation, all filter media tested produced lower effluent water turbidity. Comparing the filter media tests, it can be concluded that anthracite-sand dual-media filtration gives the best effluent water quality, longest filter run time, the smallest headloss and the lowest reduction of effluent flowrate when the Percol LT 24 polymer is used. The filter run length was limited by the filter media saturation. Based on the above performance, the anthracite-sand dual-media filter should be recommended to be used in Rossdale water treatment plant.

The fine sand (0.35 mm in size) media provides better filtration than that of existing crushed quartz sand, but it causes rapid plugging and much more frequent backwash of a filter bed. This limits its application as a suitable filter media based on limited pilot testing.

It should be noted that these conclusions are based only on this study. Further investigations are recommended before these results are used at other plants.

6 Recommendations

In order to further understand and improve the filtration operation of unsoftened water, following recommendations were made for the further studies:

1. The properties of polymers, including molecular weight and charge density, and the relationship between the properties of polymer and influent water quality should be measured for more details. The information will be very valuable to provide a deeper insight in polymer aided filtration.

2. It will be very significant to explore the roles of mixing in polymer aided filtration. The mixing not only affects the performance of polymer aided filtration, but also affects the scale-up of filtration process. Perhaps it can be said that the mixing intensity in polymer aided filtration may be a critical parameter to determine the performance of filter and operation cost. So the investigation of mixing intensity on polymer aided filtration should be emphasized in the further research.

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8 Appendix I

8.1 Filter Backwash Procedure

1. Close the filter influent valves and piezometer stop valves, totally open the effluent control valves and drain the water up to a level about 500 mm over the media, then close the effluent control valves.

2. Open the air injection valve first, then open the air valve for air scour for about 3 minutes.

3. When the air wash is finished, close the air valve, and open the effluent valve to the water backwash direction, then open the backwash valve slowly.

4. Gradually increase the backwash flow in a period of 1.5 minutes to reach a flow rate of about 38 m/hr.

5. Backwash at this high flow rate for 10 minutes and then gradually reduce the flow rate to 0 in 1.5 minutes in order to settle the media evenly.

6. After water backwash, close the water backwash valve, drain the water up to the overflow level, and then close the effluent valve.

8.2 Operation Procedure

1. Water coming from the stilling basin or the clarifier passes the influent control valves, then enters the mixing tanks.

2. The water in the mixing tanks is fed by gravity into the upper of the filters. An overflow outlet valve on the top of a filter keeps the water level constant during each run time.

3. At the bottom of a filter, the filter effluent water goes through an effluent control valve and a flowrate meter, then the water is split into two lines. One line is connected to a turbidimeter and a particle counter and the other line goes into the drain. The splitting of the line is necessary to ensure flow though the turbidimeter and particle counter is within required values.

4. After the filtration run, backwash is necessary. A backwash pressure-regulating valve controls the backwash water. An air pressure-relieving valve adjusts the air for air backwash. Both of the backwashes are introduced from the bottom of the column.

The detailed operating procedure is as following:

1. Before starting each run, check all of the valves are in the right positions.

2. Adjust the influent and effluent control valves to control the flowrate.

3. Open the computer monitoring and recording file.

4. Switch on the particle counter pumps and polymer feed pumps.

5. Record the headloss and flowrate change at the run beginning and the end.

6. After finishing each run, close the influent control valve first, and close the piezometer stop valves, finally totally open the effluent control valve to withdraw the column's water.

7. Filter backwash.

9 Appendix II

Calibration or Clean Procedure of Turbidimeter and Particle Counter

The 1720D Turbidimeter is factory-calibrated using StablCal Stabilized Formazin before shipment. The instrument must be recalibrated before use to meet the accuracy specification. In addition, recalibration is recommended after any significant maintenance or repair and at least once every three months during normal operation. The turbidimeter body and bubble trap must be thoroughly cleaned before initial use and prior to each calibration (HACH Company Manual, 1998).

Calibration Procedure of 1720D Turbidimeter

Accurately measure 1.0 liter of low turbidity dilution water or < 0.1 NTU StablCal (do not stir or mix) and pour it into the clean, dry calibration cylinder. Pour carefully to minimize bubbles.

Remove the head assembly from the turbidimeter body. Check the lamp, lens, and photocell window for scaling or filming. Clean them if necessary. Place the head assemble on the calibration cylinder.

Gently tap the cylinder and then let it stand for a minimum of one minute to free any bubbles adhering to the photocell window.

Press the MENU key to access the Main Menu. Select SENSOR MENU and press the ENTER key.

Select the sensor to be calibrated using the arrow keys and press the ENTER key.

Select CALIBRATION from the menu choices and press ENTER.

Move the pointer to the ZERO ELECTRONICS menu line and press the ENTER key.

Make sure the turbidimeter head is aligned on the calibration cylinder and press the ENTER key to continue. The display will show PLEASE WAIT for approximately 30 seconds while dark values are read. If the head is removed while PLEASE WAIT is shown on the display, go back to step 7.

Move the pointer to NORMAL CAL and press ENTER to begin the calibration procedure.

The display will prompt you to fill the calibration cylinder with deionized water. Press ENTER to begin reading the deionozed water value or, to exit without updating the calibration, move the pointer to ABOUT CALIBRATION and press the ENTER key.

Press ENTER again to accept the reading of the deionized water or < 0.1 StablCal.

The display will prompt for the calibration standard value. Enter the calibration standard (20.0 or 1.0 NTU) using the ARROW keys. Press the ENTER key.

Gently mix a one liter bottle of 20.0 or 1.0 NTU StablCal standard. Pour it into a clean, dry Calibration Cyclinder. Pour slowly and carefully to minimize bubbles.

Place the 1720D turbidimeter head assembly on the calibration cylinder containning the 20.0 NTU or 1.0 NTU stanard. Make sure it is properly aligned on the cylinder.

Gently swirl the cyclinder and let it stand for a minimum of one minute to free any bubbles adhering to the photocell window. Press ENTER to begin reading the 20.0 or 1.0 NTU value or, to exit without updating the calibration, move the pointer to ABOUT CALIBRATION and press ENTER.

Press ENTER again to accept the reading of the 20.0 or 1.0 NTU standard.

The screen will show SUCCESSFUL CAL ! Press ENTER to accept the calibration and store it in memory or, to exit without updating the calibration, move the pointer to ABOUT CALIBRATION and press ENTER.

If the 1720D detects an improper calibration, the message QUESTIONABLE CAL ! will be displayed.

How to clear the sensor of PCX Particle Counter

(Met One Product Manual, 1997)

Each on-line sensor contains a cell assembly that channels water past the laser beam. Occasionally, this cell may become dirty (or may develop a film coating), effecting the normal calibration of the sensor. If this occurs, the Calibration Fail indicator (LED on the front of the unit) will illuminate. Before cleaning the sensor, turn the power off to the sensor. Cleaning the sensor may be accomplished without opening the NEMA enclosure.

One of the most frequent causes of a dirty cell is a result of letting water dry out in the cell without cleaning, which can leave small amounts of residue from the liquid on the flow cell. For this reason, Met One ships liquid particle sensors cleaned and dry. If the cell becomes dirty or stained causing the Calibration Fail LED to come on, clean the cell as follows. This will not damage the cell.

Remove the sample line quick-disconnect fitting at the inlet port (bottom) of the NEMA enclosure. Leave the quick-disconnect connected at the top.

Insert the cleaning brush up through the bottom. The cleaning solution (diluted 10:1) should be used to enhance the cleaning and will lubricate the brush/cell. Be careful not to jam the brush. As the brush is gently inserted and twirled in the bottom fitting, it will bottom out to a stop. Repeat this step several times more, then reconnect the inlet flow connector to flush the cell.

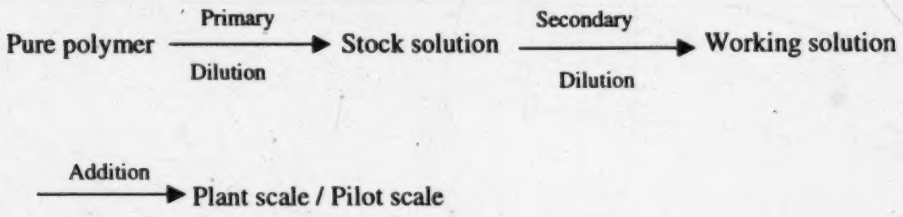
Observe the "Calibration Fail" indicator. The indicator should go off within a few seconds.

If the "Calibration Fail" indicator remains on, try "Stain" Cleaning procedure or contact Met One Customer Service Department.

10 Appendix III

Polymer Preparation

In order to simulate full-scale polymer use, dilution of polymers is necessary. First a stock solution of polymer is made. The second is to make the working solution from stock solution. Finally, the working solution of polymer was added and mixed with filter influent water in a mixing tank just before the filters.



It is recommended that stock solutions be kept no longer than two weeks, and working solution be kept no longer than 24 hours to prevent aging. The more a polymer solution is diluted, the quicker it will be degraded (Suthaker, 1995).

Preparation of stock solution:

- Pour 500 ml water into a 1000 ml clean beaker and agitate rapidly into vortex using a magnetic stir bar
- Add 1.08 g of polymer, then mix for about 12 hours to obtain 500 mL with concentration 1 mg/L stock solution.

Preparation of working solution:

- Take 20 ml of 1 mg/L stock solution and put it into a 2500 mL clean beaker.
- Pour 1980 mL water into the above beaker, then mix for about 1 hour to obtain a 0.01 mg/L working solution.

The working solution was poured into a 2-L graduated cylinder, then controlled and delivered by a peristaltic pump to a mixing tank just before the filter.

11 Appendix IV

Polymer Mixing Tank Description

The polymer mixing tank is a square jar (150 *150 *250 mm^3) with a mechanic mixer, a vertical impeller. The ratio D/T =1/3 and C/T =1/5. The impeller rotational speed N= 200- 1300 rpm and the G = 200 –2500 s^{-1}. The impeller used in this mixing tank is a paddle-blade with impeller diameter D =50 mm and width 12 mm.

Where D = impeller diameter (mm)

T = mixing tank width (mm)

C = the distance between the impeller and the bottom of mixing tank (mm)

N = impeller rotational speed (rpm)

G = Mean velocity gradient (s^{-1})

The water first goes to the polymer mixing tank where a polymer solution is supplied from the central bottom of the impeller by a peristaltic pump. After rapid mixing with the polymer, the water is then fed by gravity into the filter.